

Moneystone Quarry Report on Whiston Eaves Hydrological Impacts

Final Report

October 2021

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This report describes work commissioned by Laver Leisure (Oakamoor) Ltd, by an email dated 27/04/2021. Alex Jones and Joe Cherry of JBA Consulting carried out this work.

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Purpose

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1 Introduction

1.1 Background

JBA Consulting (JBA) have been commissioned by Laver Leisure (Oakamoor) Ltd to assess the hydrological impact of proposed future drainage arrangements at the former Moneystone Quarry, which borders Whiston Eaves SSSI and which is situated to the southwest of the village of Whiston in Staffordshire. The proposed drainage changes are part of a wider development scheme at the former quarry for a proposed leisure development for which outline planning permission has previously been granted.

1.2 Natural England Concerns

It is proposed to route future surface water drainage from the site from an outfall point near to an existing quarry void known as Q3 through an adjacent area of land which forms a Site of Special Scientific Interest (SSSI). Natural England have communicated their concerns through recent correspondence dated April 2021 (contained within Appendix A). The particular concern is in relation to the future discharge profile from the outfall at Q3 relative to the original pre-quarrying condition. This position was further clarified at a site meeting on 11th May 2021 with representatives of Laver Leisure (Oakamoor) Ltd, JBA and Natural England in attendance. Specifically, Natural England requested additional assessment of the likely average and peak flows from the site at the outfall and how these flows might compare against pre-quarrying conditions. In addition, there should be consideration about the layout of the outfall in relation to the SSSI features.

This report follows on from an interim report issued in July 2021 to Laver Leisure (Oakamoor) Ltd and Natural England by JBA. It has been updated to include additional assessment work that was undertaken to evaluate what changes in peak flows may occur because of the planned development.

1.3 Approach

Set out below is the **approach to address Natural England's** concerns in relation to discharge profiles. The findings of the assessment and in particular the predicted discharge profile can be used to support the design of the future outflow. The key tasks which have been completed to date include the following:

- review of relevant background information including topographic mapping, geological, hydrogeological and hydrological information to establish the broad physical setting of the quarry (pre and post quarrying) and the surrounding environment.
- detailed assessment of how the individual hydrological catchment boundaries have changed from before quarrying took place, to the current condition, to the proposed modifications to drainage patterns following completion of the leisure facility development
- analysis of flow data obtained from v-notch weirs on three streams (referred to as Streams A, B and C within the report), which converge within the SSSI, downstream of the quarry and form un-named tributaries of the River Churnet.
- analysis of data extracted from Lowflows2 for the pre-quarry and post-development catchments and how they relate to the recorded flow data for streams A, B and C.
- estimations of peak flow pre-quarrying using the ReFH methodology and comparing that to peak flows that would discharge from the quarry to the SSSI based upon our understanding of current proposed future drainage proposals which are proposed by Laver Leisure (Oakamoor) Ltd. The latter has been

estimated through the construction of a 1D flood modeller model (see Appendix B for further details).

The data used in the desk study were obtained from the following sources:

- Topography and general mapping:
 - OS Open Data, LDAR 1m DTM (EA Open Data);
 - Panorama Historic OS topography DTM data
- Aerial photography (Google Earth and Bing Maps).
- Geology and Soils:
 - British Geological Survey (BGS) 1:50,000 Geology Map;
 - BGS digital geology mapping;
 - BGS online borehole database (BGS website);
 - BGS online Lexicon (BGS website);
 - 1:250,000 soils mapping (Soil Survey of England and Wales, 1983).
- Hydrogeology:
 - Aquifer classification (Environment Agency / Magic Map);
 - Minor aquifers in England and Wales (Jones, 2001).
- Abbeydale (2014), Flood Risk Assessment Report – Moneystone Park Whiston Report 418040FR
- Entec 1991 – Extract – Figure E1 _ Location of Features Around Stream S3 at Moneystone Quarry

2 Baseline Assessment

2.1 Introduction

This chapter is based on information collected by JBA through a desk-based study and the site visit with Natural England representatives held in early May 2021.

2.2 Site location and description

Moneystone Quarry is located approximately 1km south-east of the village of Whiston in Staffordshire, centred at National Grid Reference SK 04553 46124 (Figure 2-1). After the cessation of quarrying in Dec 2010, the quarry site comprised a series of ponds surrounded by a mixture of wetlands, grassland, woodland and shrubland. Whiston Eaves SSSI is located approximately 300m southwest of Q3, which is the largest standing water body (formed following quarrying) within the former quarry.

2.3 SSSI

Whiston Eaves SSSI lies to the south-west and topographically downgradient of Q3. It is designated for a range of features including its species rich meadows. This citation notes:

The topography of the site is very varied because it is based around the confluence of three small tributary streams of the River Churnet which, in places, have cut steeply through the underlying Westphalian Coal Measures of the Upper Carboniferous period. Whilst some fields are almost level, others are on gentle south-west facing slopes, and one of the fields, towards Rake Edge, is on the steep, east-facing side of a valley cut by the combined stream. At the north-eastern limit of the site, and in the upper reaches of the streams, the soils overlie Rough Rock Sandstone, a seam of Millstone Grit which is also of the Upper Carboniferous. This varied topography and geology has resulted in a range of soils of variable drainage and nutrient status.

Therefore, the SSSI is sensitive to changes in the water supply mechanisms that support it. The latest condition assessment (11/05/2021) for Unit 1 immediately adjacent is classified as Unfavourable recovering and notes this status is due to 'As water levels are recovering to post-quarrying levels the springs have returned throughout this part of the SSSI. Discussions are underway with the quarry owner (via the planning process) about securing a sustainable and appropriate permanent outfall arrangement into this part of the SSSI, which will be compatible with the natural processes that the flush features and wetlands depend on as well as furthering the conservation and enhancement of this part of the SSSI.'

2.4 Topography and surface water hydrology

The ground surface within the site area slopes generally down to the southwest, with elevations ranging from approximately 131mAOD at the downstream extent of the SSSI (south-west of Q3 quarry) to a ridgeline with a high point of 293mAOD, located approximately 1km north-east of the quarry.

Figure 2-2 displays contours depicting the original ground surface before quarrying, adapted from historical OS mapping (dated 1937) reviewed by JBA, in addition to LIDAR mapping, which shows the current topography of the site. Historic quarrying activities have led to a significant change to the ground surface, which has resulted in changes to the original drainage flow paths and catchment boundaries.

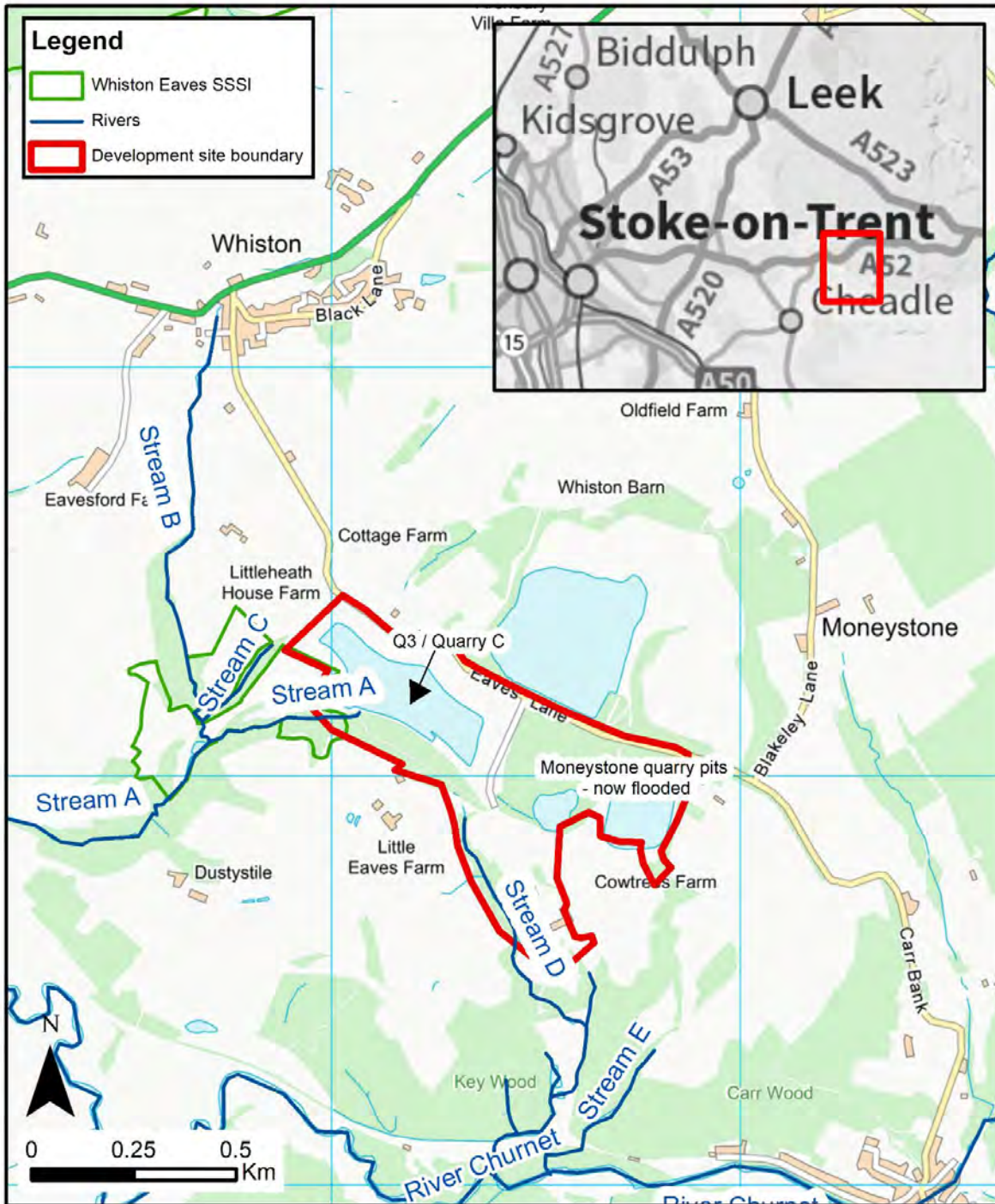
There are three main valley features within the area surrounding Moneystone Quarry with watercourses flowing towards the south-west, all of which are unnamed tributaries of the River Churnet, including:

- Stream A with tributary streams B and C in the western valley;
- Stream D in the central valley; and,

- Stream E in the eastern valley

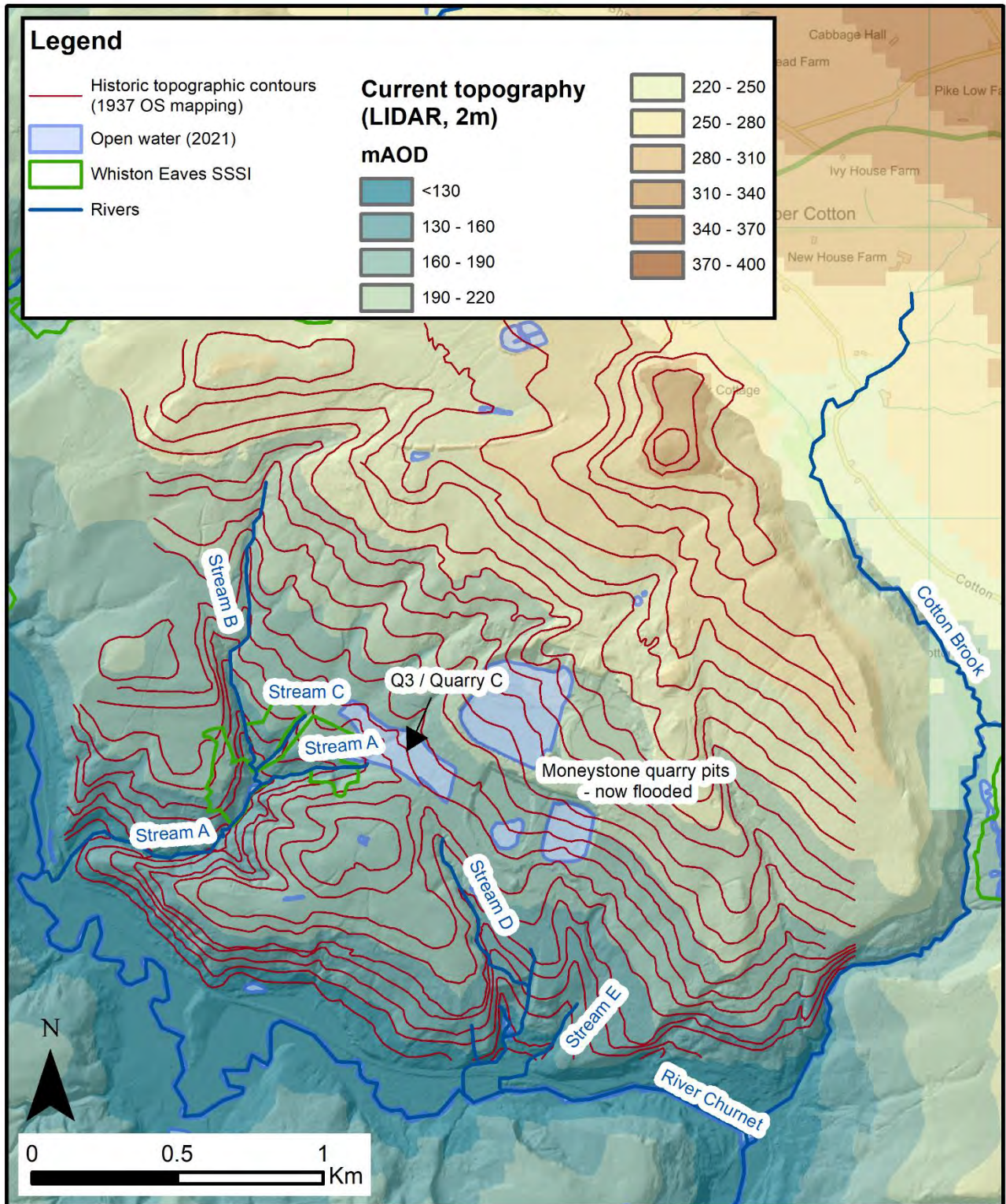
The topography and watercourses are shown in Figure 2-2 while the catchment areas are discussed further in Section 5. To the northeast of a ridge in the topography along the eastern boundary of the quarry, the land slopes down towards Colton Brook, which is also a tributary of the River Churnet.

Figure 2-1: Site location



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Figure 2-2: Topography and surface water hydrology



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2.5 Historical land use

In order to establish how the land use and ground surface has changed over time due to quarrying, historical and contemporary Ordnance Survey Maps of the area have been reviewed separately by JBA, accessed through the National Library of Scotland Historical Maps. The main developments are described in Table 2-1.

Table 2-1: Historical mapping

Map year	Features
1879 - 1956	Predominantly agricultural land on site and in the surrounding area. Whiston Eaves farm buildings located in the eastern half of what is now the Q3 reservoir. Forestry located at Whiston Eaves farm and larger areas of forest located to the south-west (location of SSSI).
1957	Quarrying activities established - pit located east of Whiston Eaves farm buildings (now pond L7).
1966	Extent of woodland (containing SSSI) increased to the north-east. Quarry still comprises one pit (now pond L7). Pit Q3 not yet established.
1988	Second pit excavated to the north of L7. Otherwise, no major changes.
1988-2010	Quarrying expanded during this time to five separate pits, including Q3 to the west of L7 and L4 to the east.
2010-2020	Cessation of quarrying, flooding of former pits (now ponds), and growth of vegetation throughout the site area.

2.6 Geology and Soils

Information on the soils and geology of the site and surrounding area has been derived from 1:50,000 BGS mapping, BGS online borehole archive and data provide by the client. The geology of the site is summarised in Table 2-2.

2.6.1 Soils

Soil classification by the Soil Landscapes Online Viewer (DEFRA, 2021) have revealed the site area to have multiple soil types. Slowly permeable seasonally wet loamy and clayey soils are located immediately south of Q3 reservoir, while freely draining slightly acidic loamy soils surround the quarry area and underlies the majority of the SSSI. In addition, freely draining very acidic sandy and loamy soils underly the eastern half of Moneystone Quarry. Within the bounds of the quarry, the natural soils do not occur.

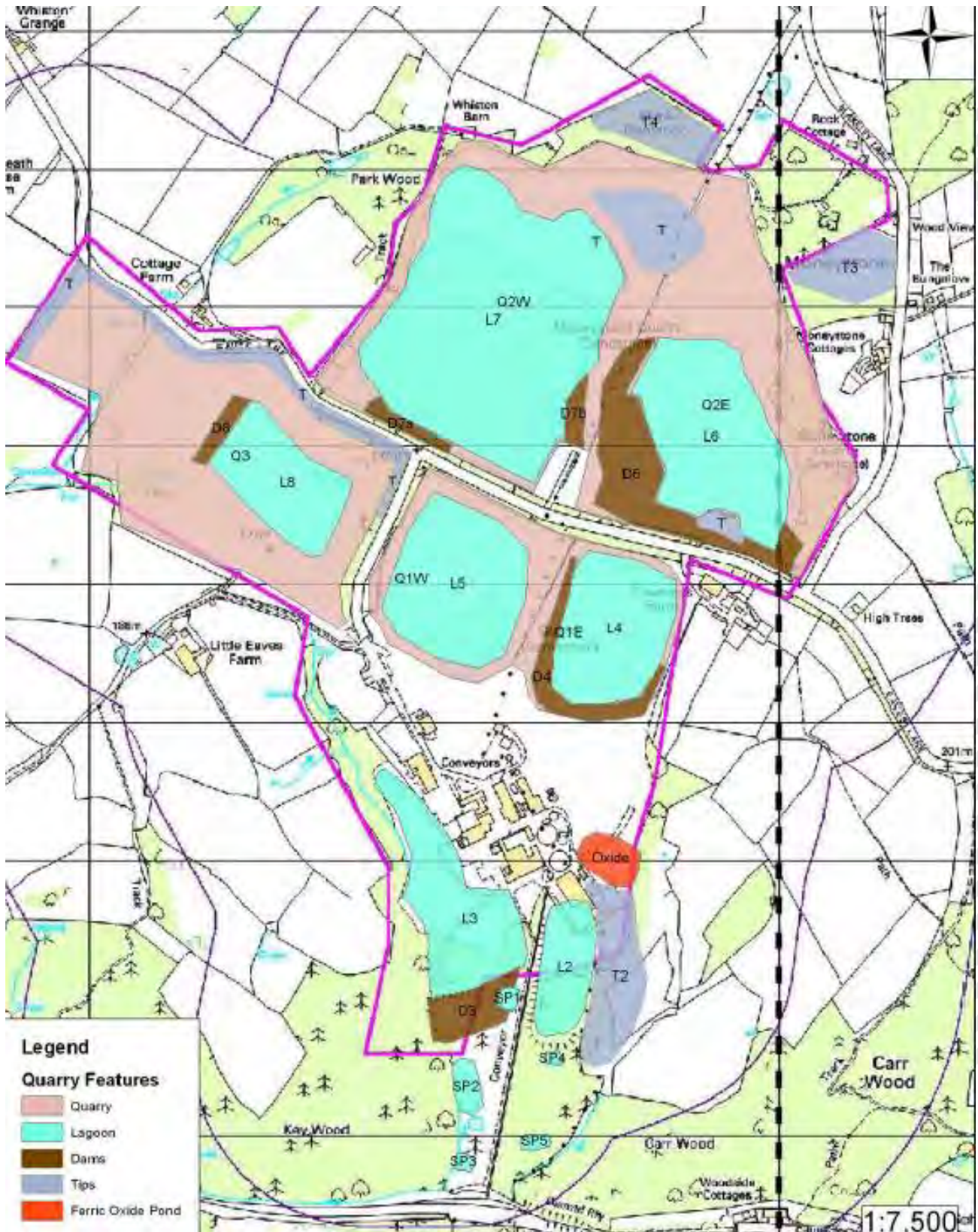
2.6.2 Superficial Geology

As a result of quarrying the nature of the superficial deposits have been significantly altered across the site area and Whiston Eaves SSSI. However, alluvium deposits line the river valley approximately 1km south-west and till deposits are located 1km north of the quarry.

2.6.3 Made Ground

Historic quarrying activities have led to a complex pattern of reworked material on site (see Figure 2-3). The figure below shows some of the main features of the quarry including the location of dams, and tipped areas. Of note is that the dam that forms a "land bridge" along the boundary of the Q3 lagoon has changed location since this figure was developed and now lies along the boundary with the SSSI.

Figure 2-3: Quarry Features (after Abbeydale 2014)



2.6.4 Bedrock geology

The site is underlain by various bedrock strata including the Pennine Lower Coal Measures and the Millstone Grit Group (Rough Rock) (Figure 2-5). Underlying the Whiston Eaves SSSI and land south of the quarry are Pennine Lower Coal Measures strata (up to 650m thick), which typically comprises interbedded mudstone, siltstone and sandstone with numerous coal seams throughout. Kingsley Sandstone and Woodhead Hill Rock (sandstone) are thin units contained with the Pennine Measures and outcrop in bands south of the quarry, generally trending north-west to south-east.

Underlying the Pennine Lower Coal Measures and exposed within the quarry and to the north is the Millstone Grit Group (approximately 150m thick), comprising fine to coarse feldspathic sandstones, interbedded with siltstones and mudstones. Within this, Rough Rock is a coarse-grained sandstone (up to 30m thick) which is exposed throughout the quarry and extends approximately 1.1km north. Also, within the Millstone Grit and underlying Rough Rock, is the Chatsworth Grit, which is a fine to coarse pebbly sandstone exposed north of Whiston.

The bedrock generally dips 9 degrees to the south-west. The area has been subjected to post-Carboniferous deformation, evidenced by a normal fault (with hanging wall to the south-west) cutting through Whiston Eaves SSSI, which trends north-west to south-east. In addition, several faults occur north of the quarry at Whiston and to the east of the site area.

Box 1 presents a more detailed description of the site geology from Abbeydale (2014). Fig 4 reference in the text is reproduced as Figure 2-3 in this report and Fig 3 is reproduced as Figure 2-4 showing the general geological sequence through the site.

Box 1: Geological Description from Abbeydale (2014)

The Geological Survey maps of the area, BGS Sheet 124 and SK04 NE and SK04NW along with memoir of the area have been examined. Information has also been gained from Geo-Environmental Desk Study (Reference No. 49) and Geotechnical Assessment (Reference No. 50). The quarry area are is shown to be underlain by the Rough Rock Sandstone of the uppermost unit of the Upper Carboniferous Millstone Grit (Namurian) Series, which is overlain by Upper Carboniferous Coal Measures mudstones and siltstones. See Fig. 4.

The Rough Rock Sandstone is fine to medium grained and is composed largely of quartz grains. The sandstone is normally hard and well cemented. However, it does contain beds and lenses of uncemented and poorly cemented weak sandstone. Also present are thin beds or lenses of shale, along with beds of very hard white siliceous sandstone. The sandstone has an on site maximum thickness of 35m, with an average dip of 5 to 7 degrees and up to 12 degrees south - southwest.

The overlying Coal Measures consisting mainly of mudstone outcrop south of the quarries and therefore cap the sandstone as the strata dips to the southwest. Examination of the quarry faces have revealed three sets of discontinuities, two joint sets striking east-west separated by 0.5m to 2m and a third set parallel to bedding. These three sets form cubic and tabular blocks of about 0.3m to 1m in size. The bedding planes and joints in the quarry face appear open, possibly due to loosening by quarrying. The exposed rocks in the tunnel have been less disturbed and indicate bedding planes to be partially open. Both will result in allowing preferential flow paths for groundwater.

The upper 15m of the medium-bedded to massive sandstone is generally pale coloured containing 0.15% iron oxide. The lower beds are red in colour due to iron oxide coating on the sand grains (0.3 - 0.5% iron oxide). Iron ore is clearly visible in the paler rocks, with chromite also recorded to be present.

Shale underlies the sandstone and forms the higher ground to the north. They then dip under the sandstone and are up to 4m below the base of Q1E, Q1W and Q2E and

Q2W. See Fig. 3.
 The site is not underlain by drift deposits whilst residual soil is recorded to be approximately 0.5m thick. Made ground associated with the infilling of the quarry voids is in excess of 20m thick and largely comprises of clay slurry with a cap of 2m to 4m of solid mainly granular quarry waste.
 The Crowtrees Fault lies near to the eastern boundary of the site. The fault is trending north - south and has downthrown strata approximately 20m to the west, resulting in the sandstone being uneconomic in this area. A further fault is recorded to the southwest of Q3 and downthrows the strata to the southwest.

Figure 2-4: Geological Cross Section After Abbeydale (2014)

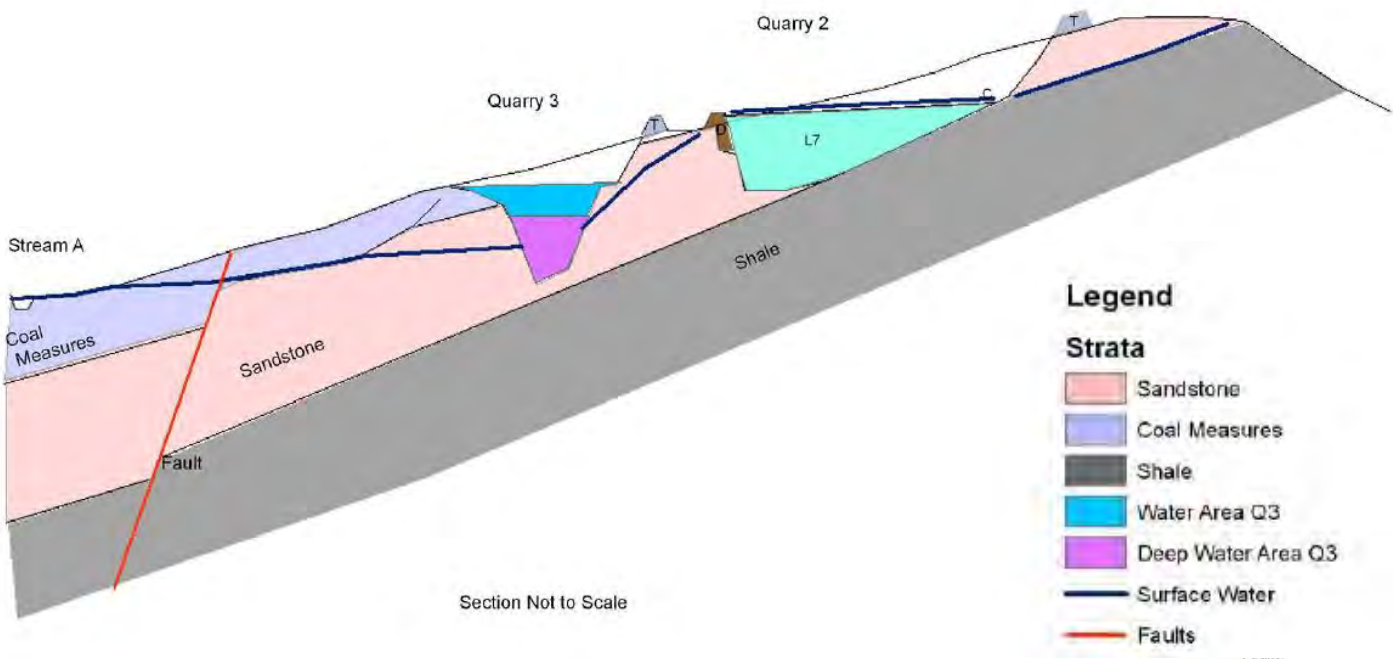
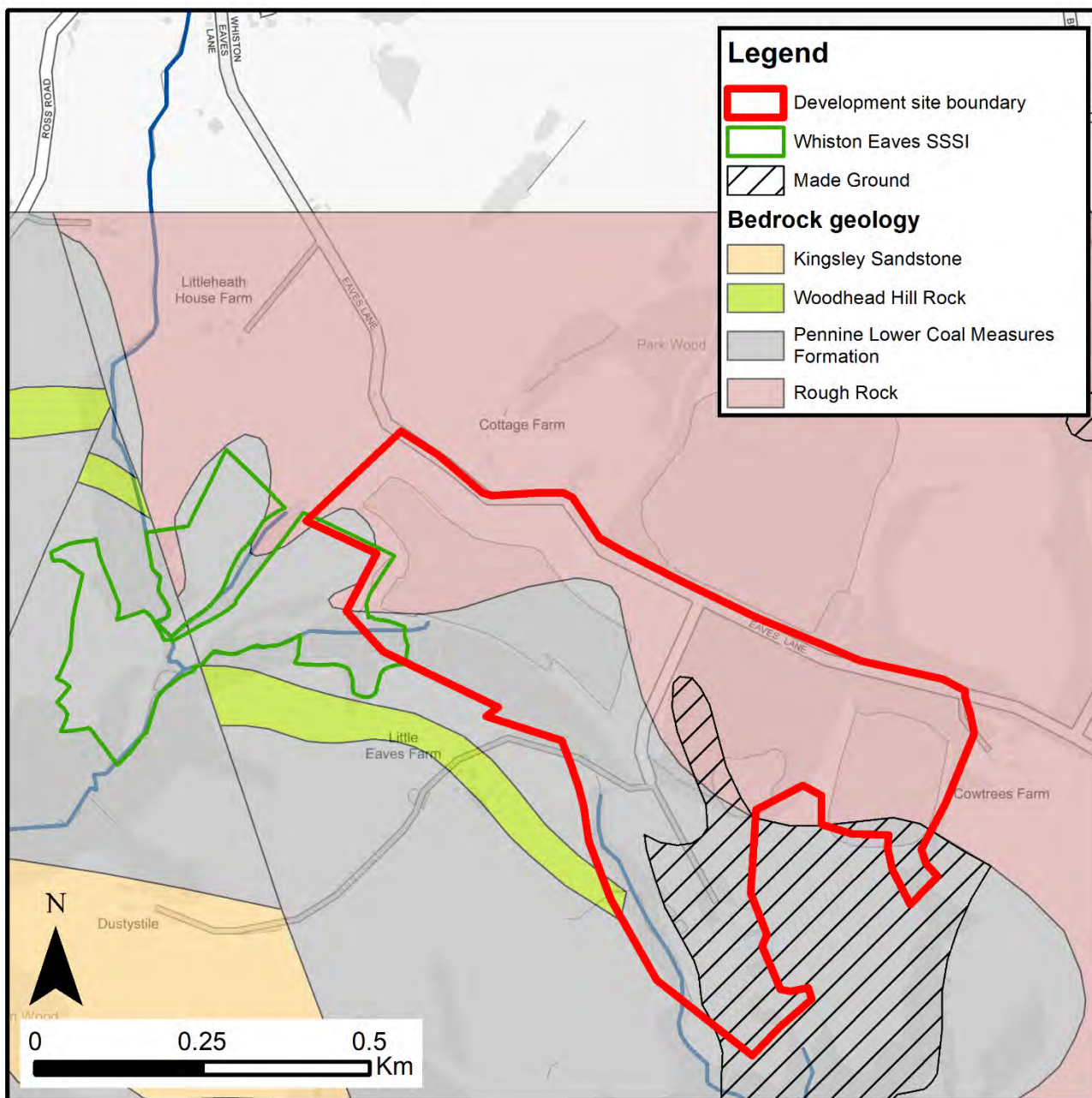


Table 2-2 - Summary of site geology

Age	Group	Formation / Member	Description	Thickness
Quaternary	Superficial deposits	Topsoil	Slowly permeable seasonally wet loamy and clayey soils (located immediately south of Q3 reservoir) Freely draining slightly acidic loamy soils (surrounds the quarry area and underlies the majority of the SSSI) Freely draining very acidic sandy and loamy soils (eastern half of Moneystone quarry)	Thin / absent on areas of active quarrying
		Alluvium	Deposit only occurs approximately 1km south of Moneystone Quarry	Unknown
		Till	Deposit only occurs approximately 1km north of Moneystone Quarry	Unknown (likely thin)
Upper Carboniferous	Pennine Lower Coal Measures (Kingsley and Woodhead included within)	Pennine Lower Coal Measures	Interbedded grey mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part, and more numerous and thicker coal seams in the upper part*	Up to 650m*
		Kingsley Sandstone	Sandstone*	Unknown
		Woodhead Hill Rock	Sandstone*	Unknown
	Millstone Grit Group (Rough Rock and Chatsworth Grit included within)	Millstone Grit Group	Fine- to very coarse-grained feldspathic sandstones, interbedded with grey siltstones and mudstones, with subordinate marine shaly mudstone, claystone, coals and seatearths*	Approximately 150m*
		Rough Rock	Coarse grained, cross bedded, feldspathic Sandstone*	Up to 30m*
		Chatsworth Grit	Fine to coarse grained, massive and cross bedded, locally pebbly sandstones, with minor interbedded mudstone and siltstone	Up to 90m*
Source: * BGS Lexicon of Named Rock Units				

Figure 2-5: Bedrock geology



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2.8 Hydrogeology

2.8.1 Aquifer designation and properties

The alluvium deposits lining the River Churnet are designated Secondary A Aquifers, which are permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. The till deposits to the north are designated Secondary Undifferentiated, meaning the layer has previously been defined as both minor and non-aquifers by the Environment Agency in different locations due to the rock's variable characteristics.

All of the Upper Carboniferous units which outcrop within and near the site are collectively designated Secondary A Aquifers. Both the Pennine Lower Coal Measures and Millstone Grit Group are multi-layered aquifers, with permeable sandstone aquifer units interbedded with lower permeability siltstones and mudstones. The BGS Baseline Report Series (Abesser, 2005) describes the Millstone Grit as an important local aquifer providing water for potable and industrial use. The sandstone units are well cemented and it is understood that groundwater storage and flow is predominantly through joints and fractures (Abesser, 2005).

Abbeydale (2014) make the following comments regarding the hydraulic properties of the Rough Rock sandstone:

The permeability of the sandstone has been recorded within a range of values, field tests record the permeability of the sandstone to be 4.3×10^{-3} to 4.3×10^{-1} m/sec. As these results are quite high, this probably represents quite a large volume of fracture flow as well as bulk sandstone permeability. We would estimate the permeability of the sandstone itself to be in the order of 10^{-5} m/sec, with a calculated permeability based on rainfall data, catchment areas and lag time to peak stream flows of 1×10^{-4} to 2×10^{-4} m/sec. The permeability of the tailings is estimated to be in the order of 10^{-8} m/sec.

2.8.2 Spring, Seepages and Sinks

Across the area are a series of springs, seepages and sinks. This section describes this pattern and relates this to our interpretation of the anticipated position of the water table within the units. Figure 2-6 to Figure 2-9 present the following:

- Figure 2-6 and Figure 2-8:
 - Two selected groundwater contour plots showing the maximum (December 2003) and minimum (October 2002) levels from thirteen individual groundwater monitoring rounds conducted between 1997 and 2004. The boreholes are recording general levels within the Rough Rock.
- Figure 2-7 and Figure 2-9:
 - The mapped location of sinks across the quarry.
 - The location of seepages within the SSSI based on a 1997 Entec survey.
 - The maximum and minimum depth to the water table determined through comparing the pre Q3 LIDAR data from the groundwater contour levels.
 - The position of the bedrock boundary between the Rough Rock and overlying Pennine Lower Coal Measures strata.

From this the following is evident:

- The seepages observed within the SSSI:
 - are likely to be from individual higher permeability units within the Lower Coal Measures.
 - in the upper part of the SSSI, the water table within these higher permeability units lies above the estimated position of the water table within the Rough Rock in high and low groundwater conditions.
 - The sink within the base of the SSSI is a possible pathway to the Rough Rock water table.
- Within the East of the Quarry,
 - the lagoons (i.e. flooded quarry voids) vary from being perched (i.e. disconnected) to being expressions of the surrounding water table.
 - the elevation of the mapped sinks are consistently higher than the main sandstone water table.

Overall, the pattern of sinks suggests that there is little surface water lost to ground until it reaches a sink.

Figure 2-6: October 2002 Groundwater Contours within the Sandstone

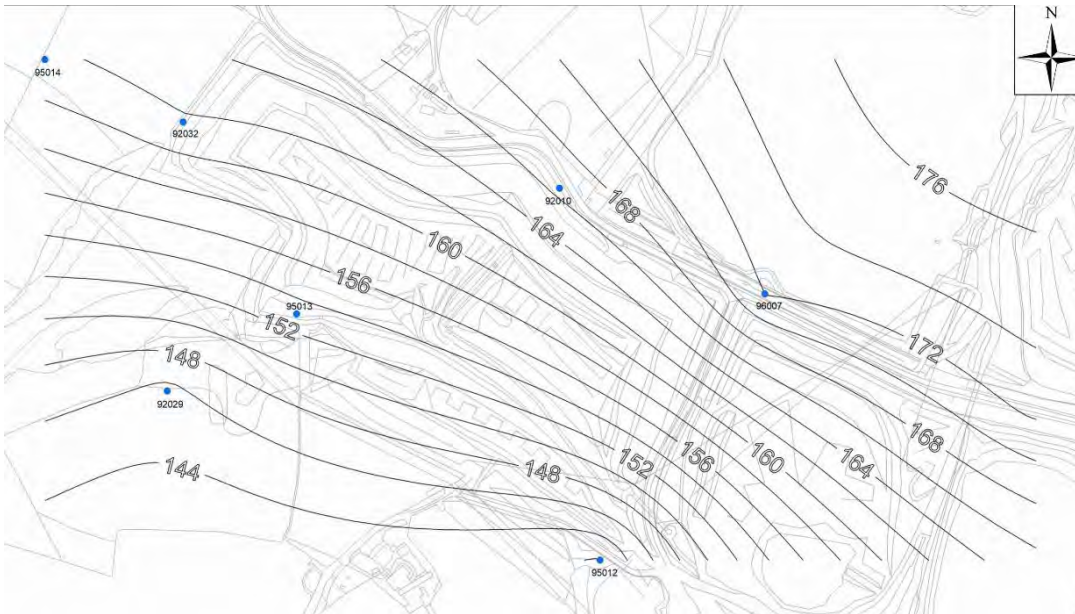


Figure 2-7: October 2002 Depth to Groundwater, bedrock boundary and Location of Sinks and Seepages

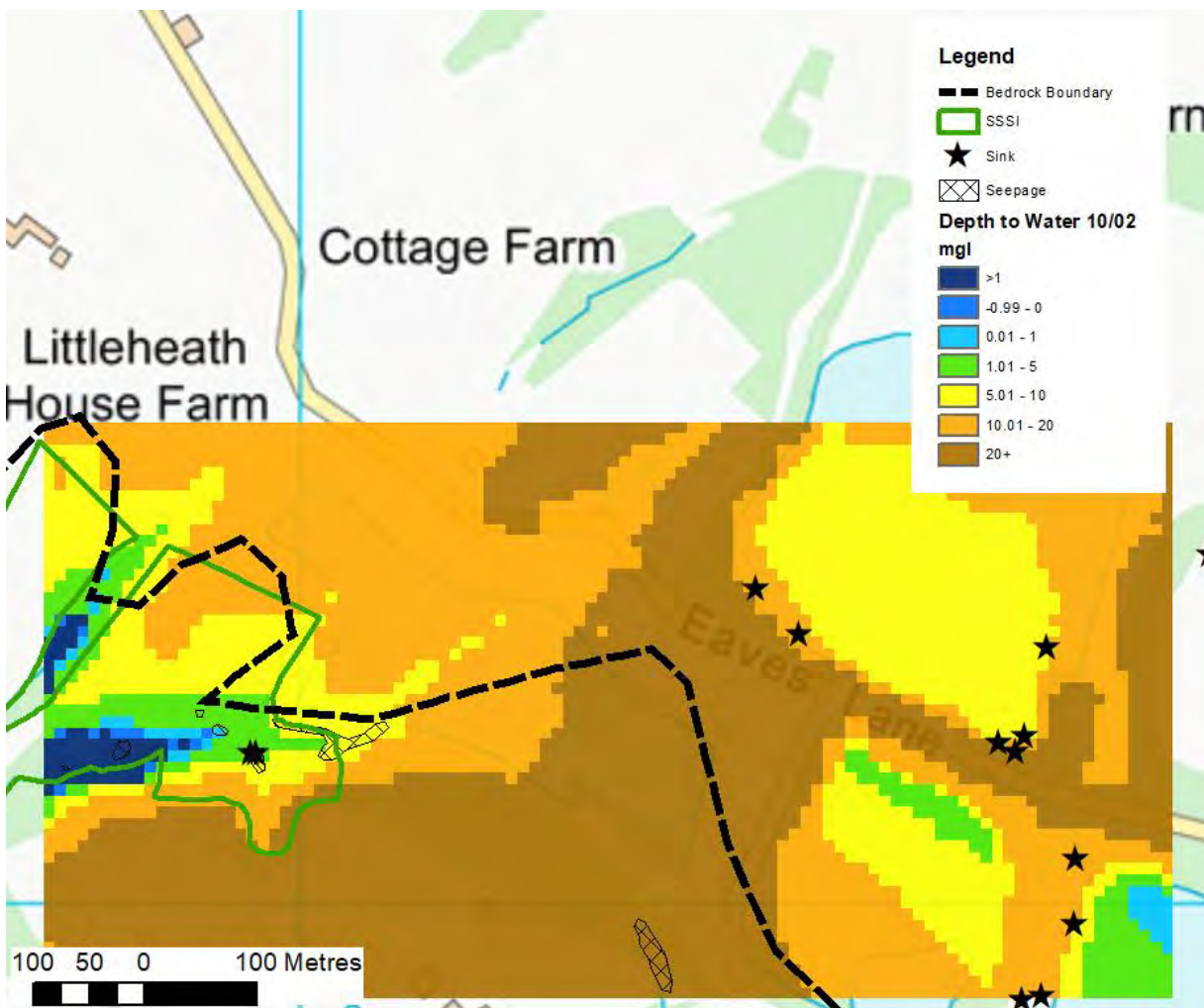
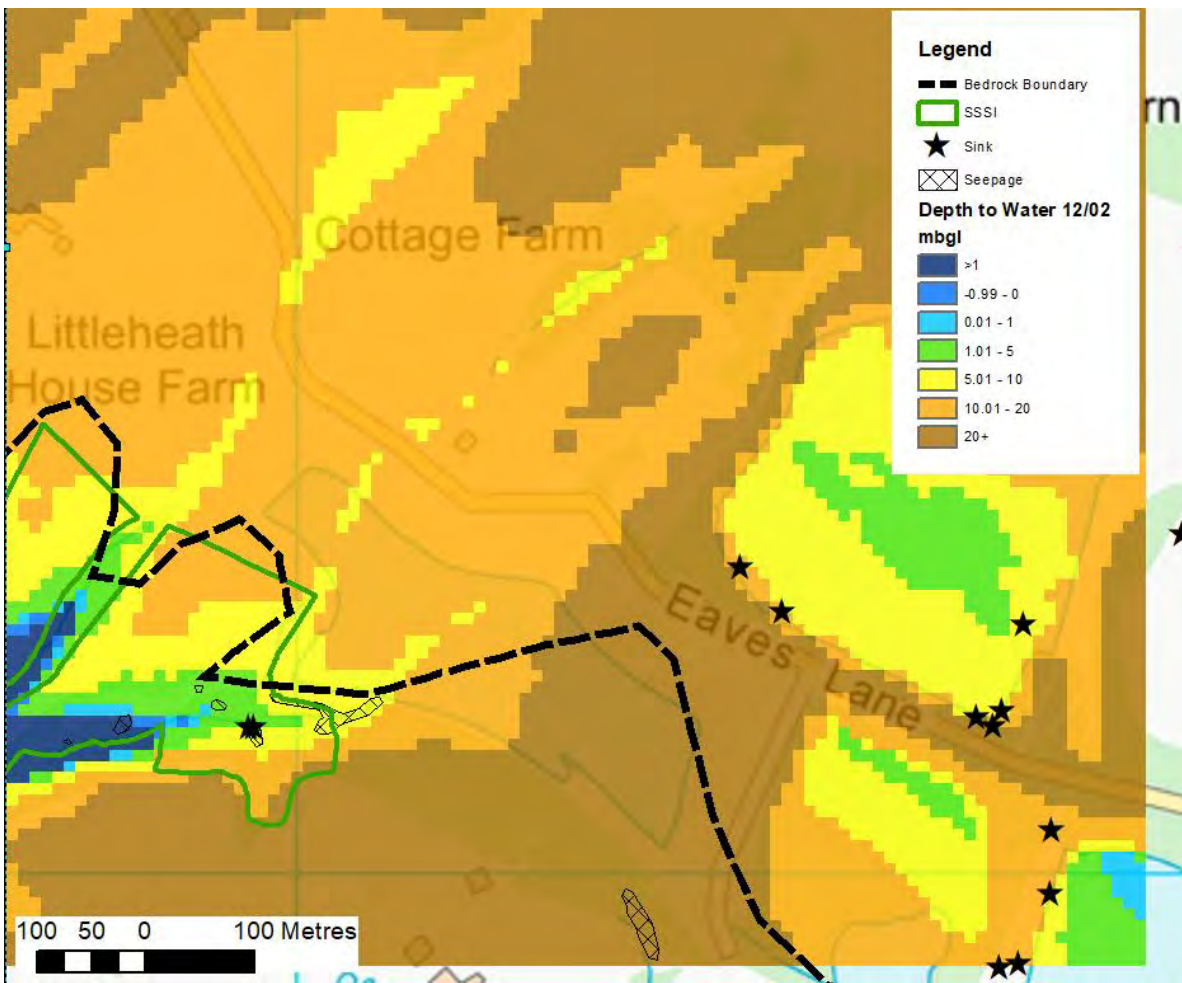


Figure 2-8: December 2003 Groundwater Contours within the Sandstone



Figure 2-9: December 2003 Depth to Groundwater, bedrock boundary and Location of Sinks and Seepages

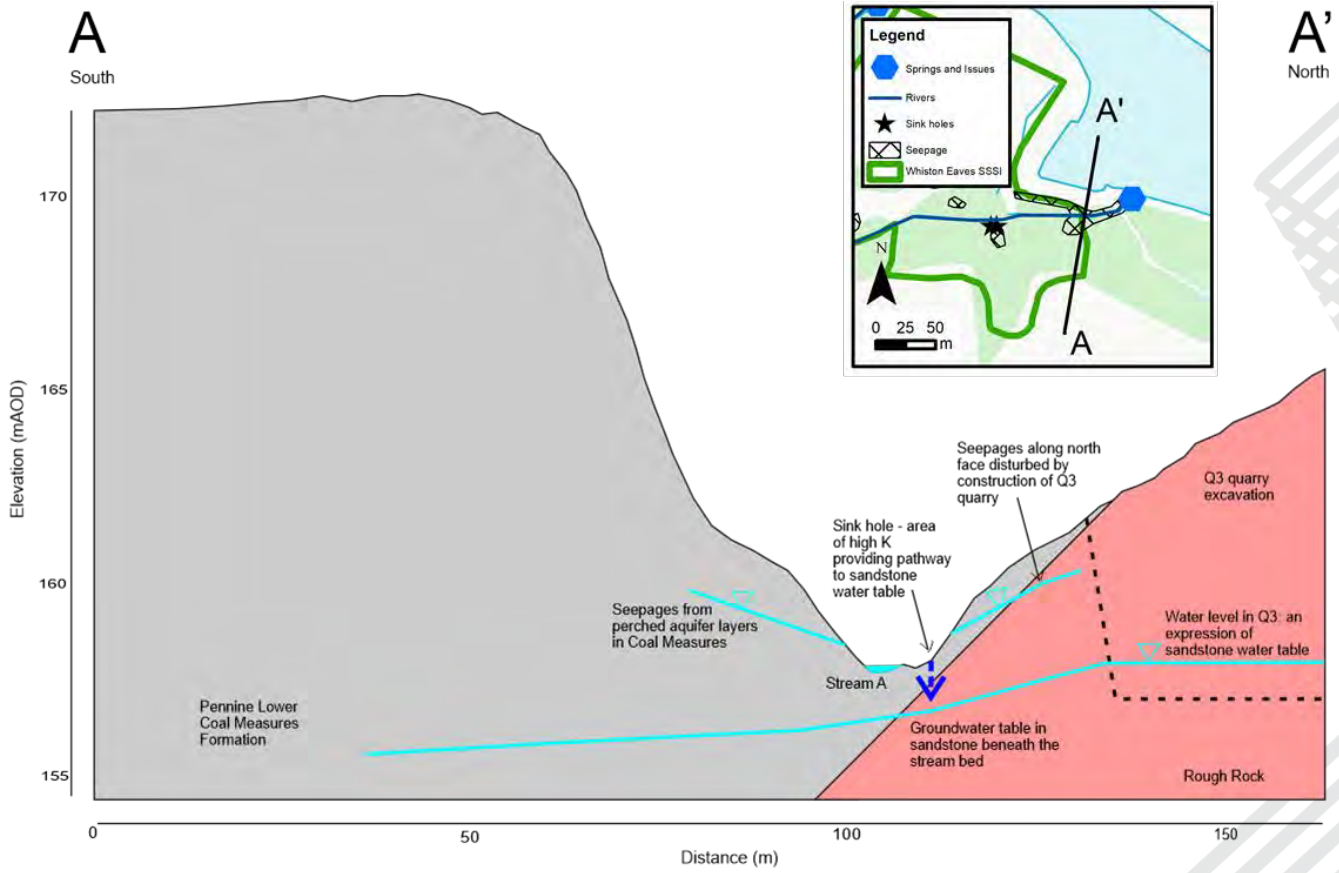


3 Hydrogeological Conceptual Model

A hydrogeological conceptual model is "a description of how a hydrogeological system is believed to behave" (Environment Agency, 2002). It describes "how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system" (Rushton, 2003). The hydrogeological conceptual model for the site is shown in Figure 3-1 and has the following features:

- Topography:
 - The ground surface was extracted from LIDAR and depicts the slope prior to excavation of the Q3 quarry. The cross section shows a north-south view through the Stream A valley (which flows down to the west).
- Geology and hydrogeology:
 - Rough Rock (sandstone in which fracture flow is the dominant flow mechanism) underlies the northern part of the section and dips approximately 9 degrees south-west. The Pennine Lower Coal Measures overlies the Rough Rock to the south. Both units are designated Secondary A aquifers.
- Sinks and seepage:
 - Seepage (discharge) faces are located across the north and south side of the Stream A valley and are from higher permeability units within the bedrock.
 - The water table within these higher permeability units lies above the water table within the Rough Rock in high and low groundwater conditions. It is likely that the higher permeability units form a series of discrete aquifers.
 - The pattern of sinks (across the whole site) suggests that there is little intergranular permeability within the sandstone. There is little surface water lost to ground until it reaches a sink.
 - Further downstream of the sinkholes in the SSSI, the position of water table within the Rough Rock is at or above the ground surface.

Figure 3-1: Conceptual model cross section



4 Assessment Process

The previous sections provide a baseline understanding of the hydrological, hydrogeological and geological conditions of the proposed development and the SSSI. The following sections provide a series of analysis to assess the impacts of the development on the SSSI:

- o Section 5 – Assesses how the surface water catchments have changed in the past and how they would change in the future with the development.
- o Section 6 – Assesses how the low flows to the SSSI have changed in past and how they would change in the future with the development.
- o Section 7 – Assesses how peak flows to the SSSI have changed from pre quarrying conditions to those that may result because of the proposed drainage solution from an outfall at Q3.
- o Section 8 assesses the hydrological requirements of the outfall locations into the SSSI

5 Catchment boundary changes

5.1 Introduction

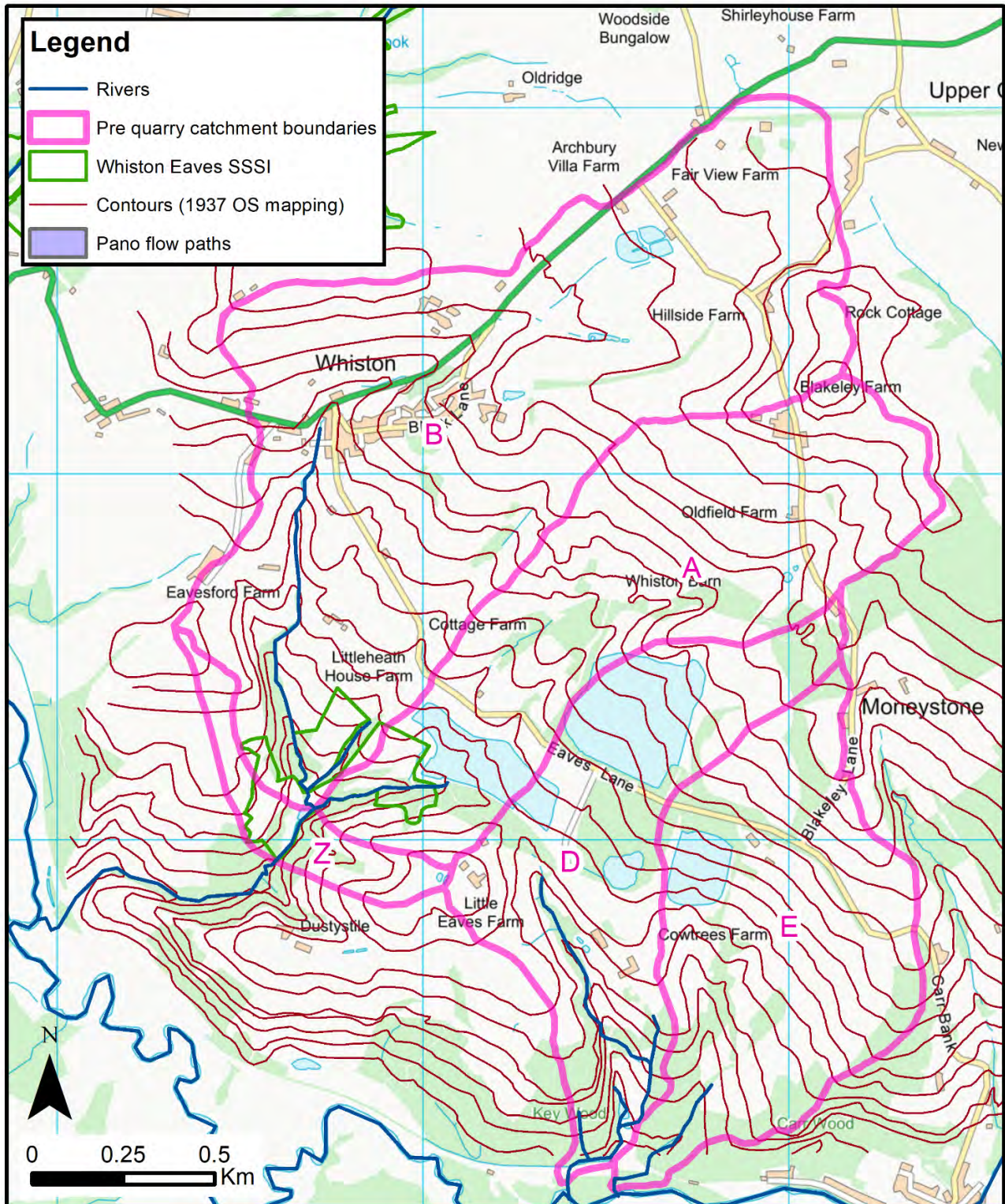
Several unnamed tributaries of the River Churnet flow through the Moneystone Quarry development site area, predominantly in a south-easterly direction. The catchment boundaries for these streams have altered over time due to the changed ground surface profile from quarrying, hence altering the surface water drainage paths and catchment boundaries.

To understand how the catchment boundaries have changed, this section considers the catchment boundaries at three points in time: pre-quarrying (pre-1957); current conditions; and proposed catchments following completion of the new leisure development. Catchment Areas are displayed in Table 5-1 while the estimated percentage change in area (derived from scaling of mapping extracts described below) from pre-quarry to existing and proposed catchments (post development), is shown in Table 5-2.

5.2 Pre – quarry catchment boundaries

OS maps prior to the start of quarrying (pre – 1957) show topographic contours of the landscape, which have been used in conjunction with the OS Panorama DTM dataset to delineate the catchment boundaries. The OS Panorama DTM is a now superseded DTM that was based on the contours on OS contour maps, and thus was based on the topography before the quarry was established. In addition, flow paths were computed in ArcGIS using the Panorama dataset to help distinguish the likely surface drainage paths. The pre-quarry catchments are displayed in Figure 5-1.

Figure 5-1: Pre-quarry catchment



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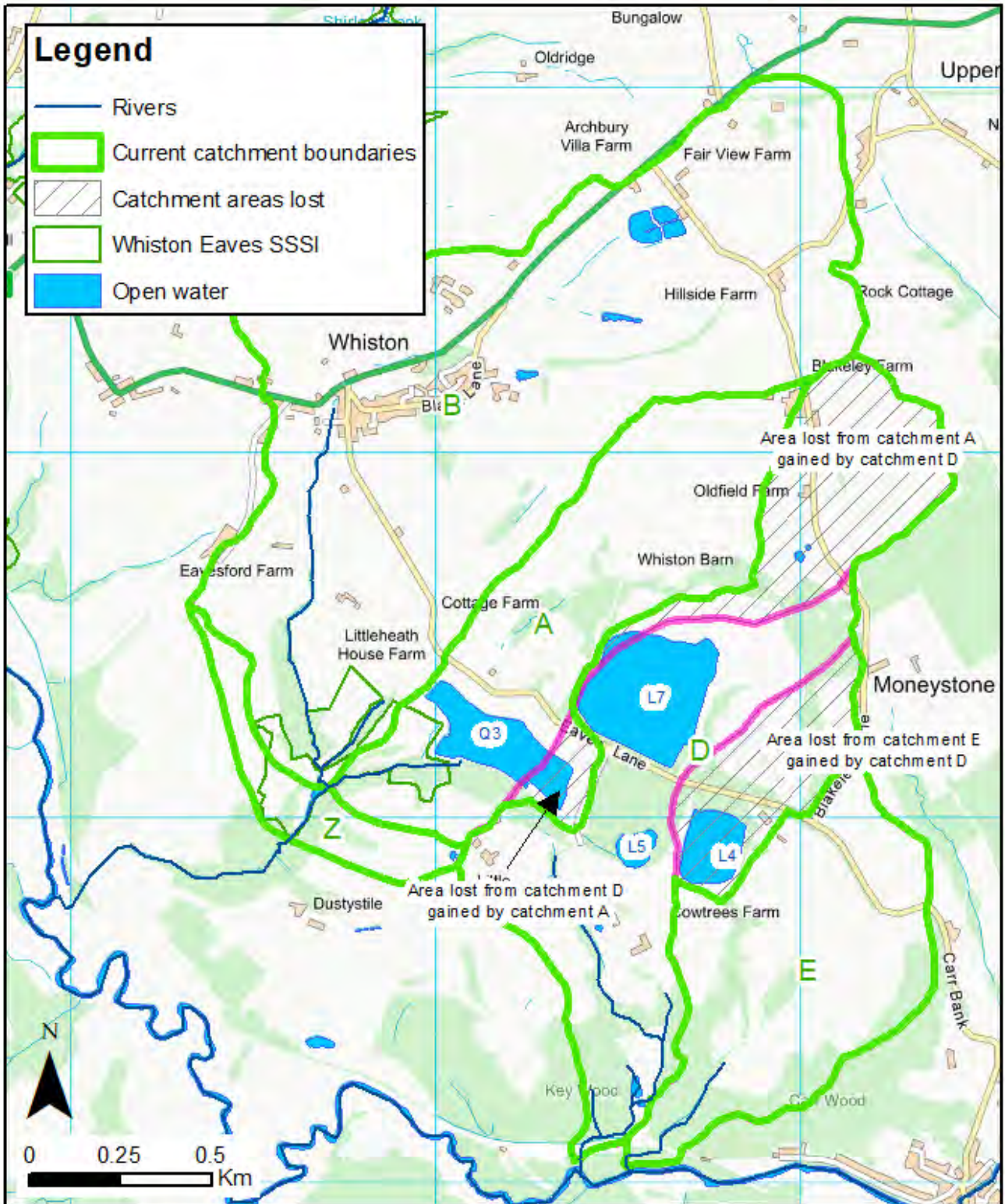
5.3 Current catchment boundaries

Flow paths were derived from a LIDAR survey (2m) to provide a depiction of the likely drainage routes of surface water throughout the catchments, following excavation and movement of the ground surface (It should be noted that the LIDAR was captured before the Q3, so the impact of this phase was manually adjusted). These were used to delineate new catchment boundaries and subsequent changes in catchment Areas (Figure 5-2).

The main changes since the pre-quarry condition includes an estimated 26.7% reduction in the size of Catchment A and a 71.7% increase in Catchment D. Due to the excavations north of Eaves Lane, flow paths to the north-east have changed from flowing west past Oldfield Farm in Catchment A, to flowing south towards the quarry pits, hence the reduction of Catchment A and increase in Catchment D in the northern headwater areas.

In addition, pit L4 (adjacent to Cowntrees Farm) has a drainage pipe in the south-west corner, thereby routing flows from the pond westwards towards pit L4. Therefore, the flow paths north of L4 are now considered part of Catchment D instead of catchment E as depicted in the pre-quarry catchments.

Figure 5-2: Current catchments



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5.4 Proposed catchments post development

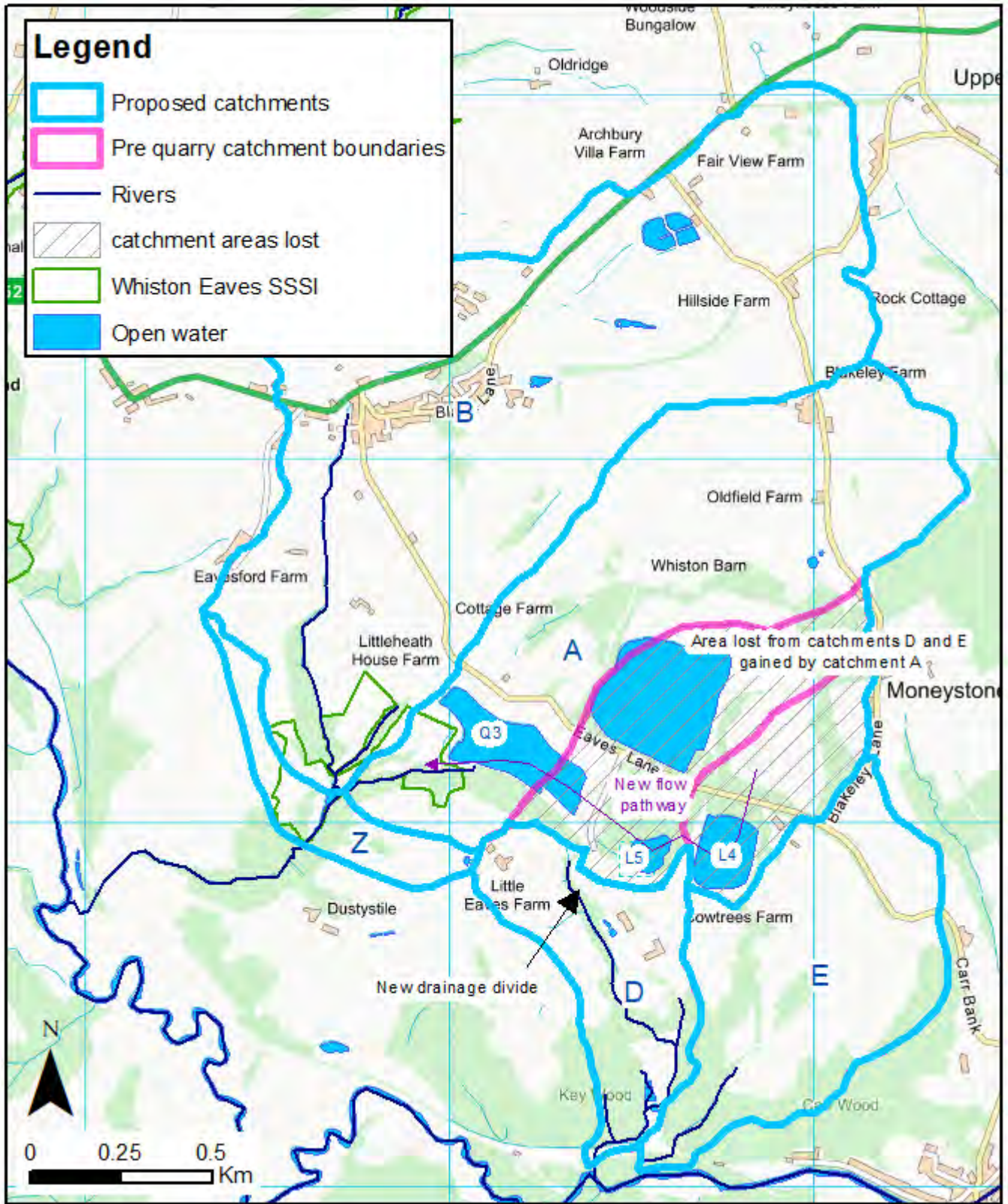
The outline drainage strategy associated with plans for the new leisure park development describes the proposed pathways for surface runoff within the site. Based on these plans, the catchment boundaries will change as the current flow paths have been diverted. Figure 5-3 displays the anticipated catchment boundaries based upon JBAs understanding of current development proposals.

It is understood by JBA that surface runoff from the area surrounding the Hub building and car park, will attenuated by the L4 pond to the north, while drainage channels along the roads will also flow into the L4 and L5 ponds. Water will then flow westwards from L4 to L5 and eventually Q3 through a network of open channels.

Therefore, this strategy will effectively create a west-east drainage divide through the middle of what is currently catchment D. Flows north of the drainage divide will be incorporated into a larger catchment A, while the reduced catchment D will comprise flows from south of the divide.

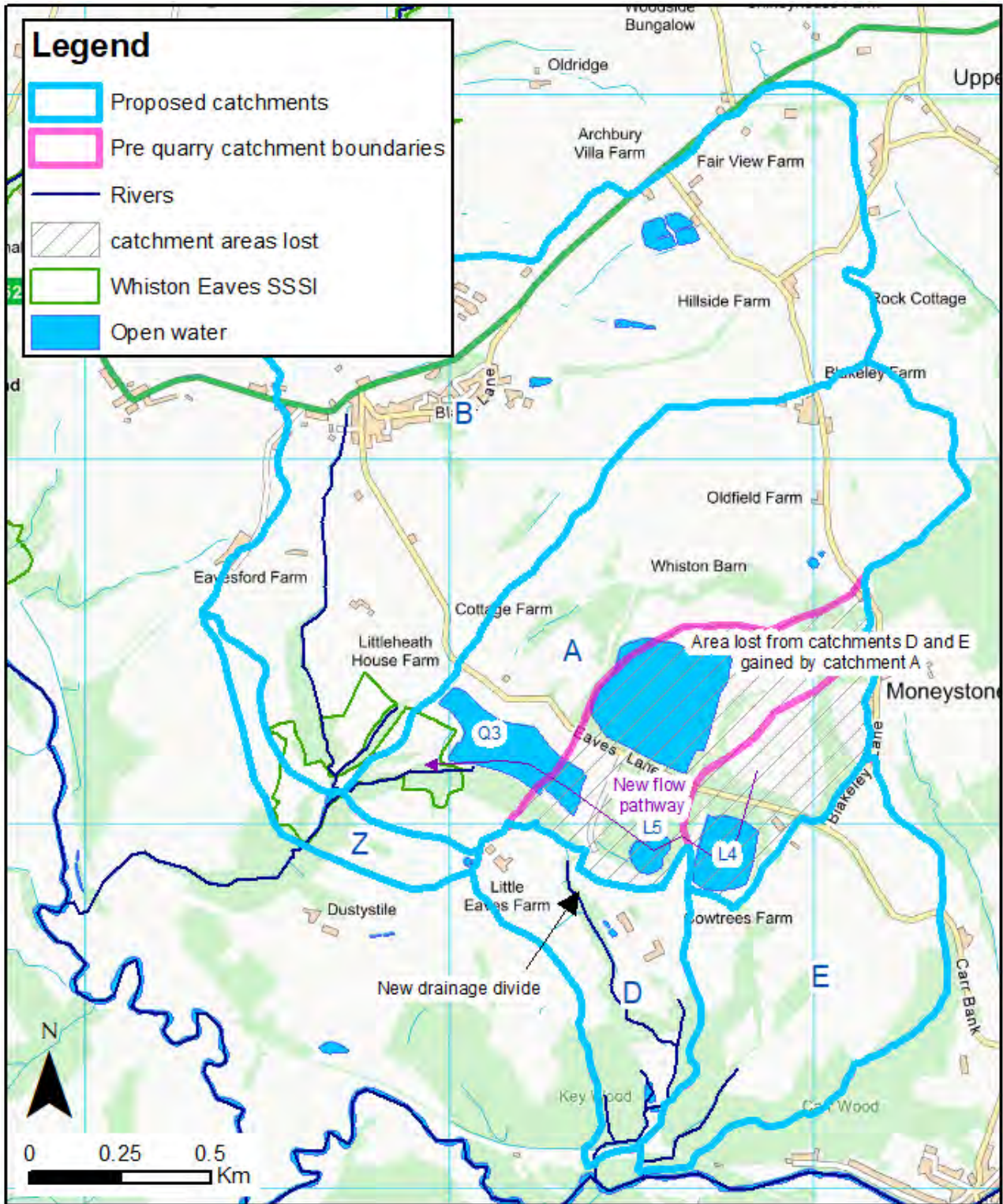
Figure 5-4 shows the difference between the pre-quarry and proposed catchment areas, where catchment A will effectively be "gaining" area from both catchments D and E.

Figure 5-3: Proposed catchments



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Figure 5-4: Proposed catchments vs pre-quarry catchments



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Table 5-1: Catchment Areas

Catchment boundaries	Pre quarrying catchments (km ²)	Current catchments (Km ²)	Proposed catchments (Km ²)
Z	2.61	2.37	3.14
A	0.86	0.63	1.39
B	1.63	1.63	1.63
D	0.6	1.03	0.27
E	0.7	0.5	0.5

5.5 Implications of catchment area changes

Table 5-2 shows Catchment A increases in size by 120.6% when comparing current conditions to the proposed catchment, and when comparing pre-quarry to the proposed catchment there is an increase of 61.6%.

Table 5-2: Estimated Change in catchment Areas

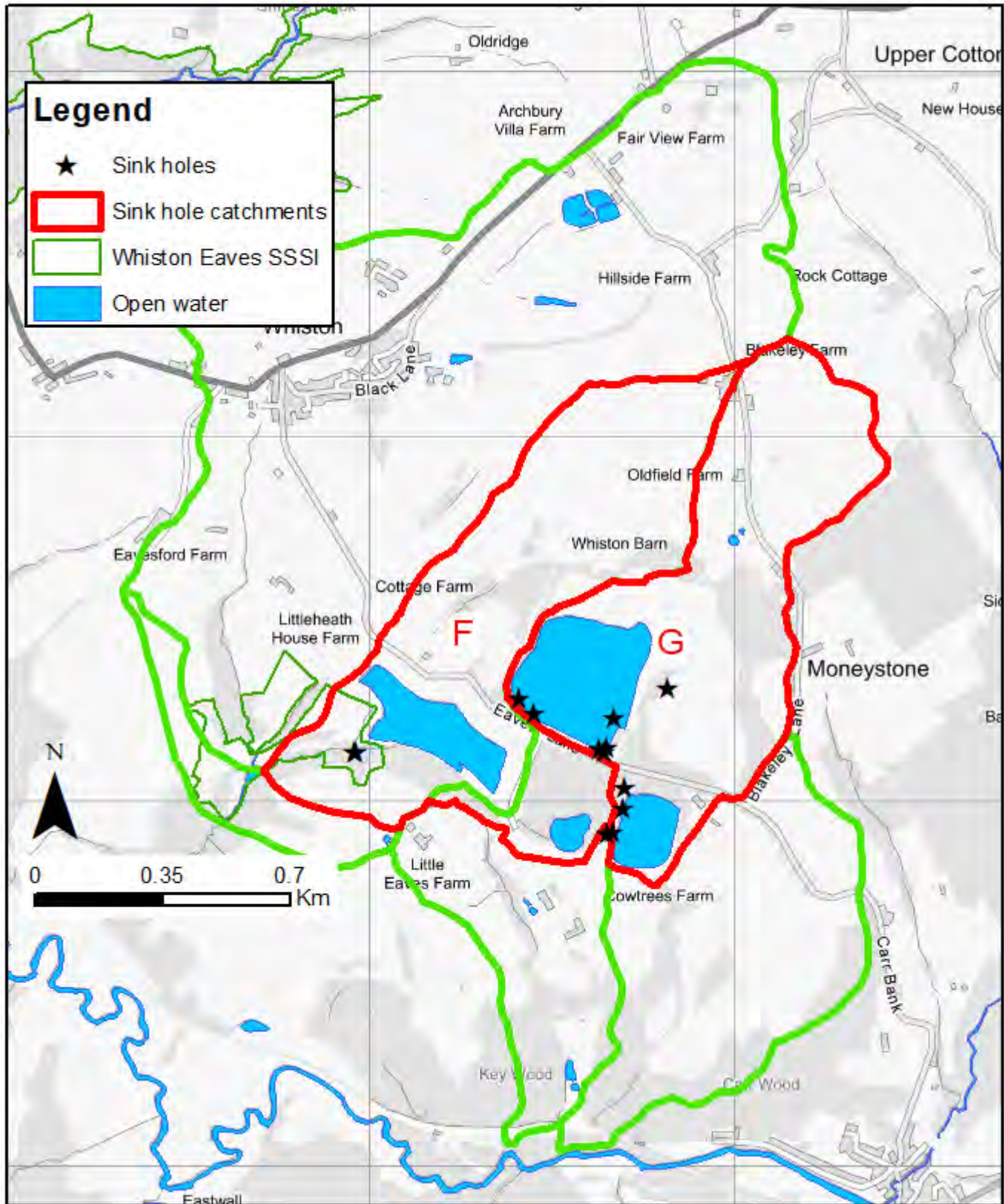
Catchment ID	Differences					
	Pre vs current		Current vs Post		Pre vs Post	
	Km ²	%	Km ²	%	Km	%
Z	-0.24	-9.2	0.77	32.5	0.53	20.3
A	-0.23	-26.7	0.76	120.6	0.53	61.6
B	0	0	0	0	0	0
D	0.43	71.7	-0.76	-73.8	-0.33	-55
E	-0.2	-28.6	0	0	-0.2	-28.6

5.6 Sink catchments

Multiple sinks where surface water is lost to the underlying ground are present in the vicinity of Moneystone quarry and their approximate locations based upon our review are shown in Figure 5-5 (see Section 2.8.2). The sinks potentially act as a significant surface runoff drainage pathway. However, the actual extent of their influence is not known. Catchment boundaries have been drawn to illustrate the potential area affected by the sinkholes (Figure 5-5).

It is likely that the sink holes capture a portion of total overland flows, thereby reducing the actual flows predicted by the modelling results, particularly at low flow conditions. Given the mapped location of the sink holes and the groundwater flow paths in the underlying bedrock (see Section 2.8.2), it is not unreasonable to expect that surface water run-off lost to these sinkholes would eventually discharge to Stream D as baseflow and not to Stream A.

Figure 5-5: Quarry Sink catchment



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6 Low Flow Analysis

The following section outlines the following:

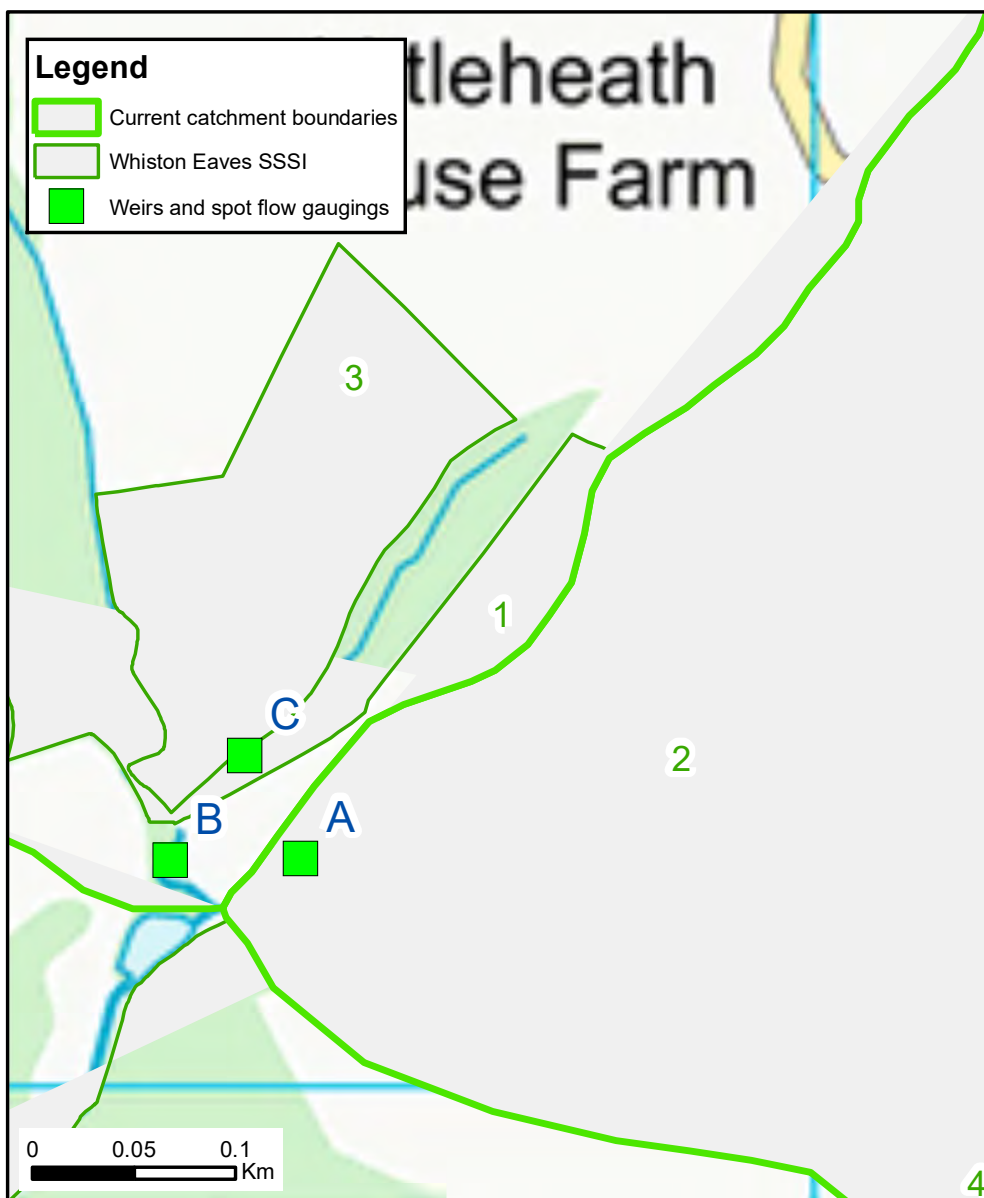
- o Section 6.1 describes the actual and modelled flow data sources,
- o Section 6.2 first compares the actual versus modelled flow data and considers the modelled flow data to predict how the proposed development would potentially alter flows to the SSSI.

6.1 Data Sources

6.1.1 Gauge locations

Three V-notch weirs are situated on Streams A, B and C (see Figure 6-1), just upstream of where they converge. Spot flow measurements at these locations have been taken at irregular intervals throughout the period from 1996 – 2021.

Figure 6-1: Gauge locations



6.1.2 Lowflows2

Flow data for the pre, current and proposed catchment areas has been obtained using the Lowflows2 software (Wallingford Hydro Solutions (WHS), 2021). The software utilises a variety of hydrological models developed jointly by CEH, the EA, SEPA and NIEA. The models have been adapted by WHS to incorporate the most recent hydrological datasets and output from WHS Research and Development projects (WHS, 2021). When importing a catchment boundary, Lowflows2 can estimate the annual and monthly flow duration statistics (Q0.1 to Q99) for the natural flow regime.

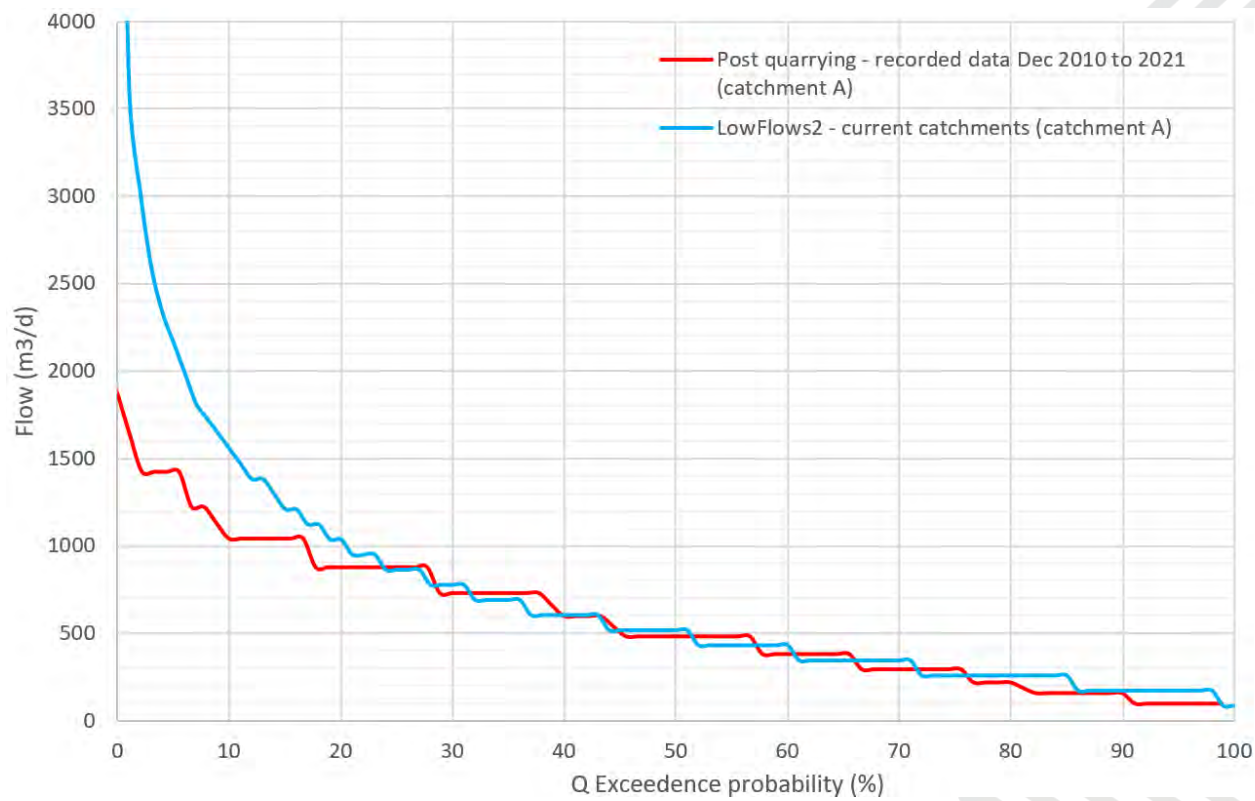
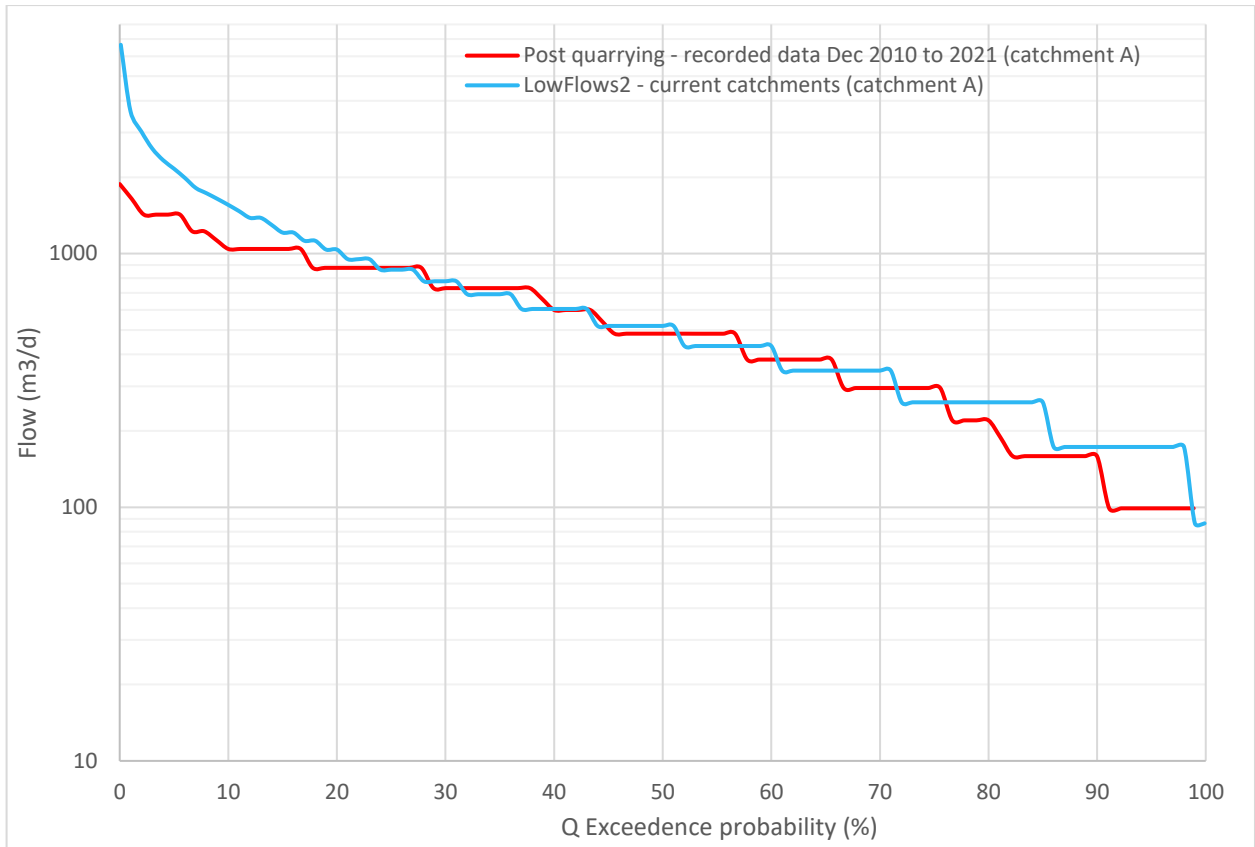
6.2 Flow Analysis

Flow duration curves for the pre-quarry, current and proposed catchment are displayed and discussed in the sections below. These are based on the catchments as described in Section 5.

6.2.1 Recorded vs modelled (Lowflows2) flows

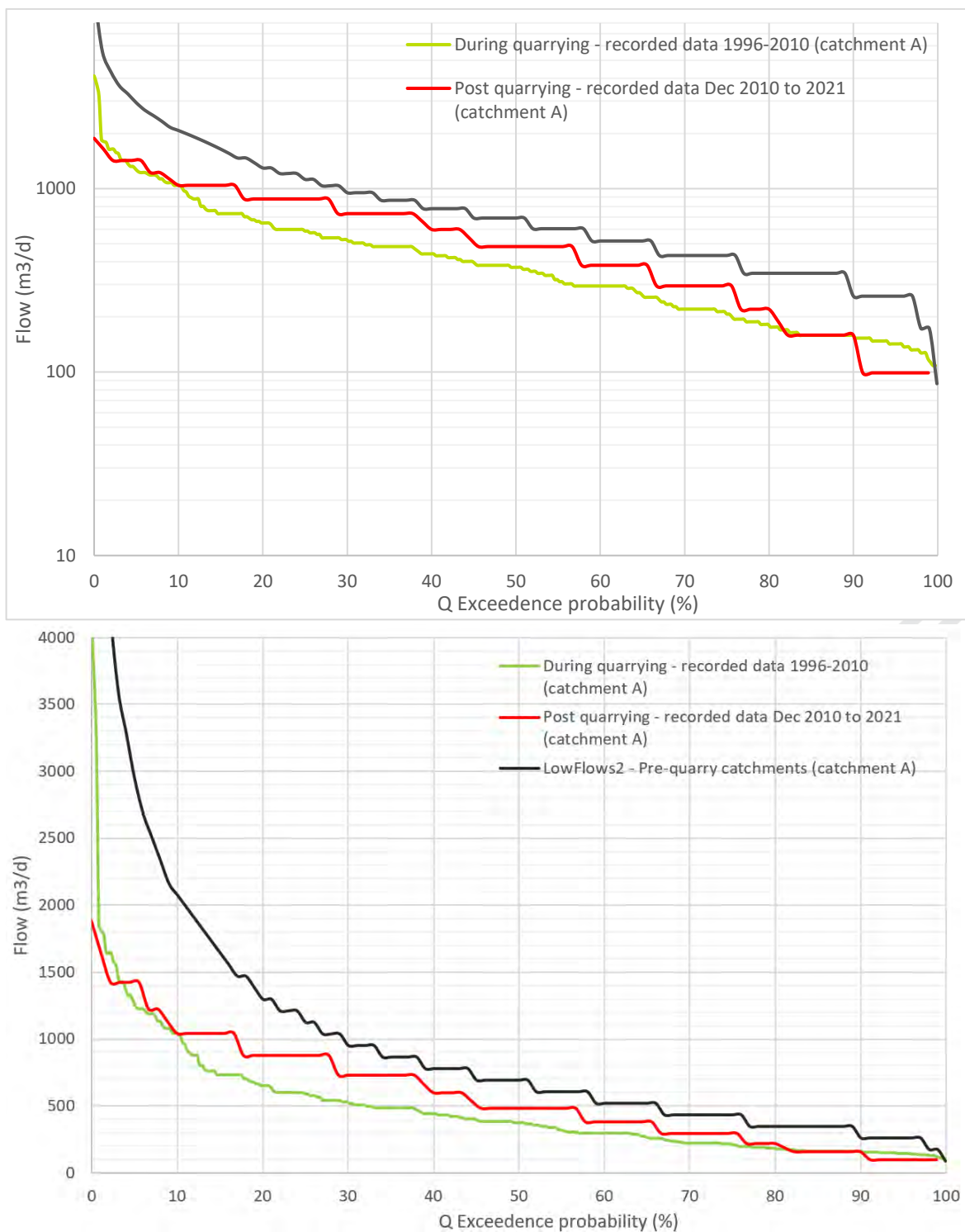
Figure 6-2 present Flow duration curves gauged and modelled (lowflows2) flows for Catchment A. Results comparing the recorded flows for Stream/catchment A during the post quarrying period of 2010 – 2021 are shown together with the modelled flows for Catchment A. From Q0.1 to Q10, which are the flows at which only 0.1-10% of flows exceed, the modelled data greatly exceeds the highest flows recorded at the stream A gauge for this period. This is most likely due to a limited number of flow measurements taken at the times of peak flow conditions. However, from Q20 to Q80 the flows show a good correlation, indicating that the modelled flows can be used as a meaningful indication of flows for proposed catchments.

Figure 6-2: Current catchments – recorded vs modelled flows



In Figure 6-3, modelled data for the pre-quarry Catchment A shows higher flows than the recorded data either during or after quarrying. This is likely a result of the reduction in catchment area caused by quarrying activities (reduction by 26.7%) and more attenuation due to the quarry ponds.

Figure 6-3: Pre-quarrying, and current catchments with recorded and modelled flows



6.2.2 Proportional changes: flows vs catchment areas

Figure 6-4 shows the prediction of the changes in flow as a result proposed development plans. The predicted flows are uniformly slightly higher than the historic or current flows.

Figure 6-4: Pre, current and proposed catchments with recorded and modelled flows

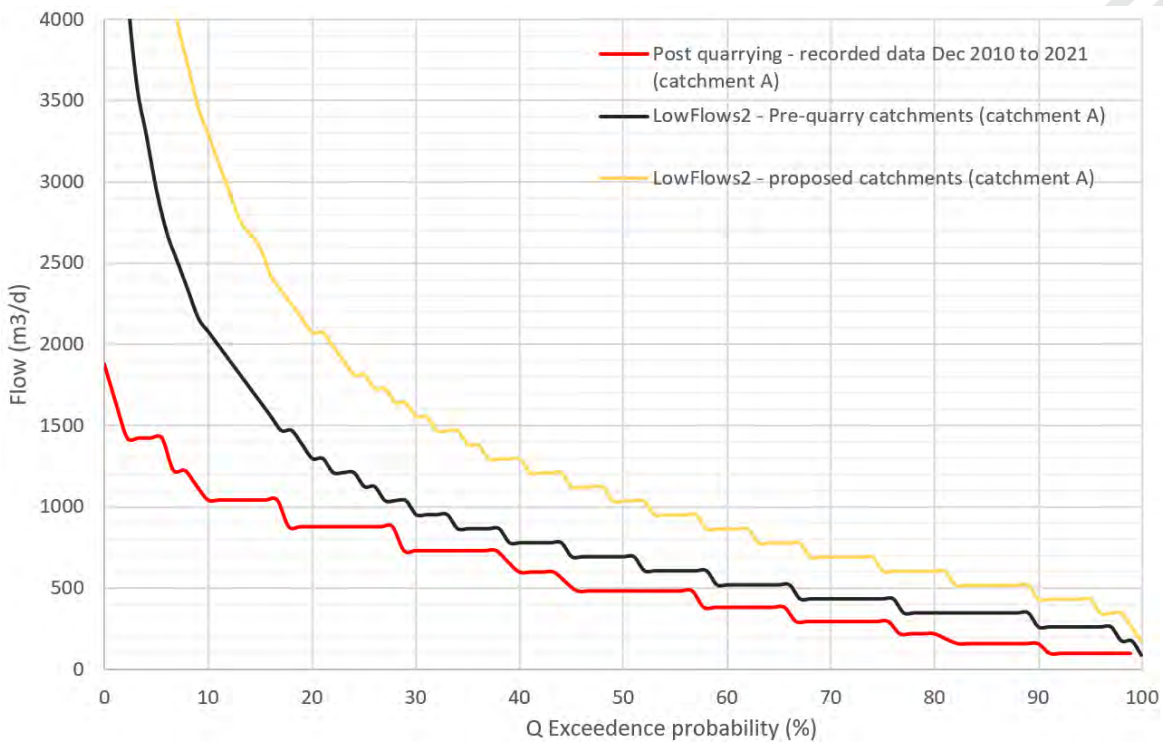
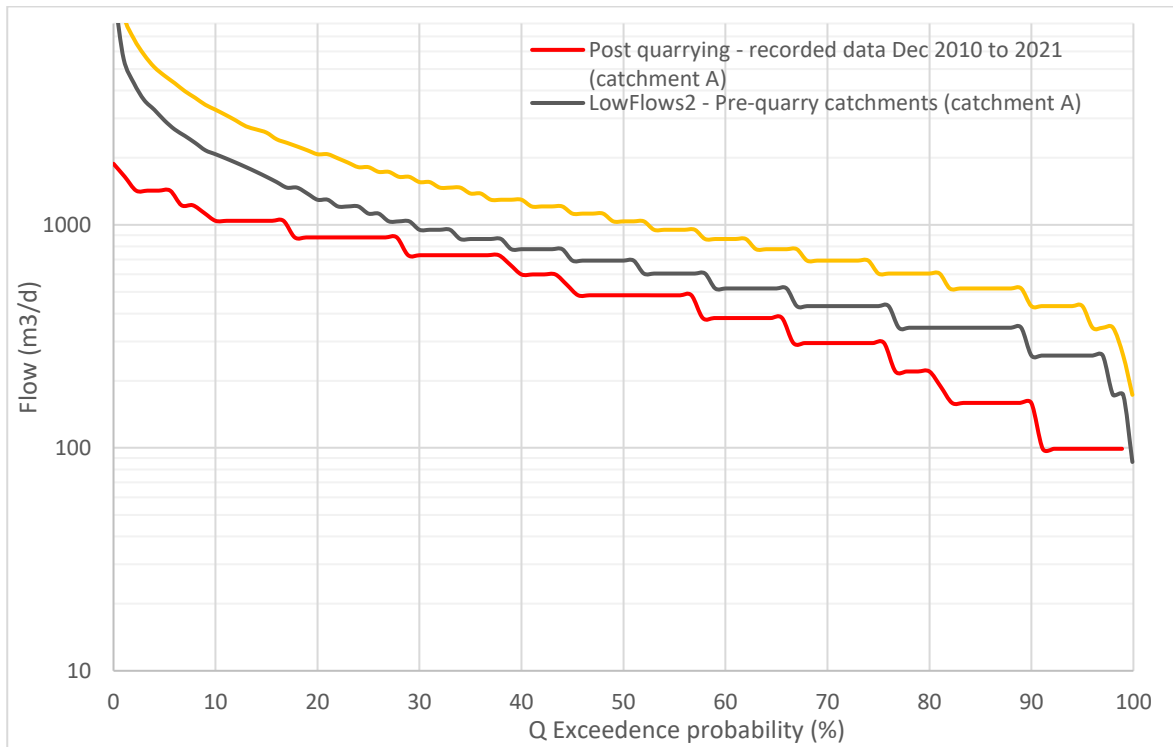


Table 6-1 displays a comparison between the percentage changes in flows and catchment areas for three scenarios in Catchment A: pre-quarrying vs. current catchments; current vs. proposed (post development) catchments; and pre-quarry vs proposed (post development) catchments. Overall, the similarities in percentage changes illustrates that the changes in catchment area is directly proportional to the flows in catchment A.

Table 6-1: changes in flows vs catchment areas

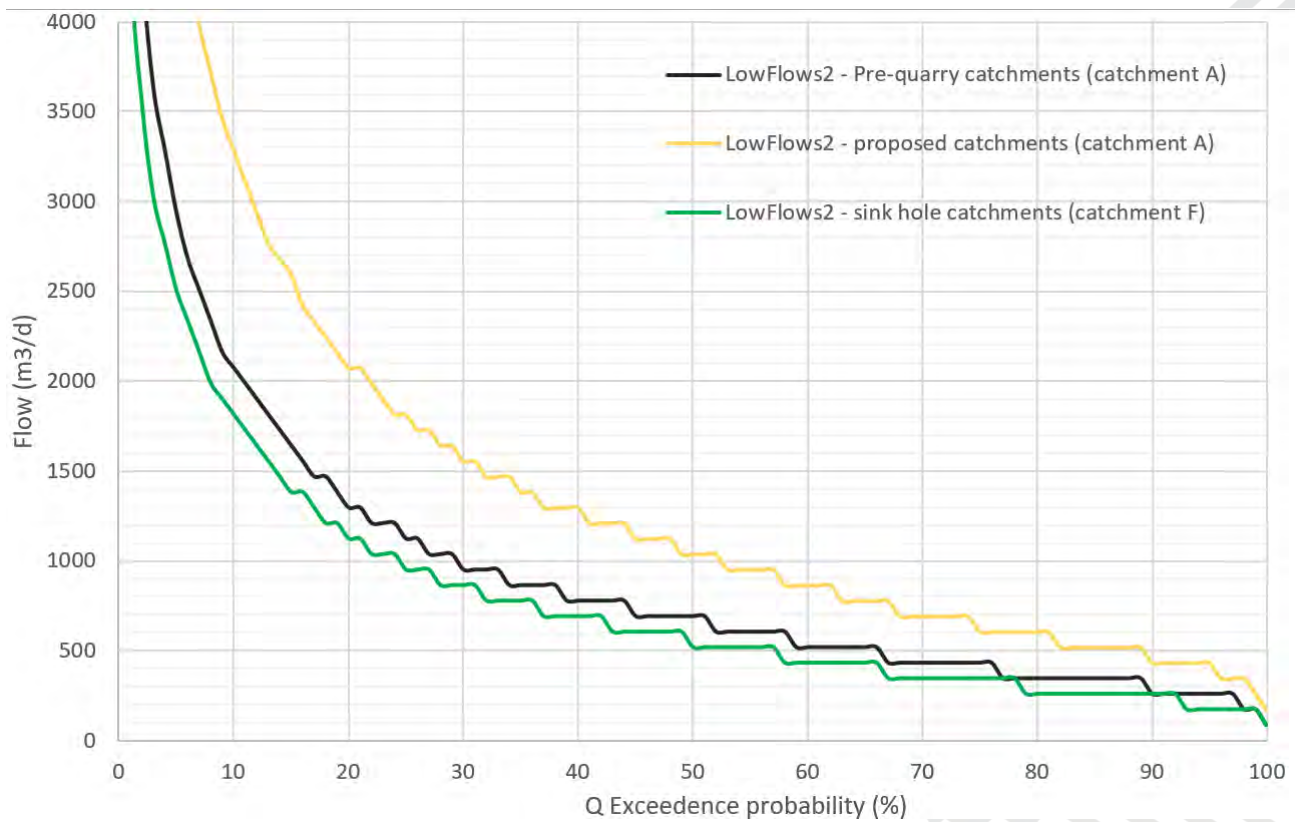
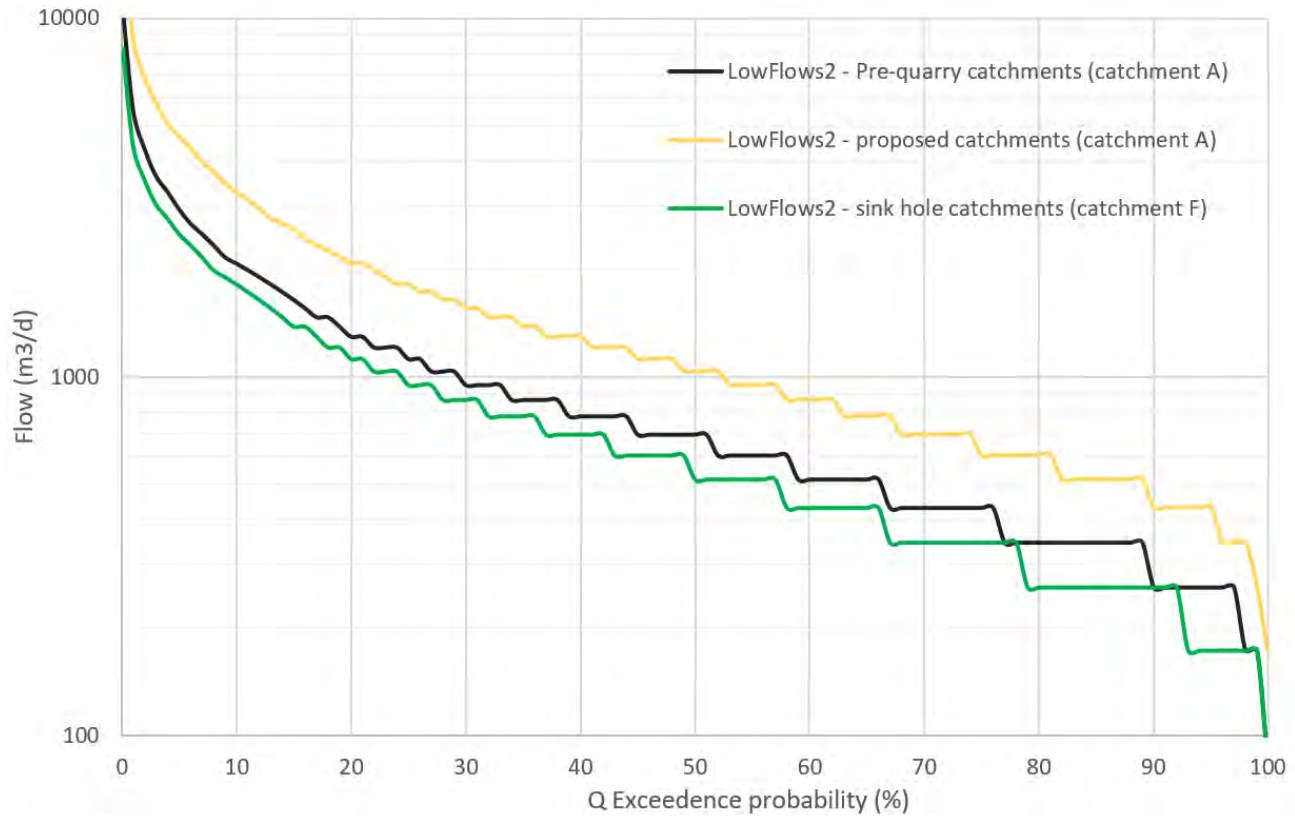
	Pre-quarry vs current (%)	current vs proposed (%)	Pre-quarry vs proposed (%)
Q10 Catchment A flows (Lowflows2)	-25	111	58
Q50 Catchment A flows (Lowflows2)	-25	100	50
Q95 Catchment A flows (Lowflows2)	-33	150	67
Catchment A areas	-26.7	120.6	61.6

6.3 Sink hole catchment flows and significance

Figure 6-5 shows the flows extracted from Lowflows2 for the sink catchments F (see Figure 5-5). Catchment F effectively represents the post-development catchment A minus the area predicted to be affected by sinkholes (named catchment G). It is reasonably anticipated that a significant proportion of flows within Catchment G, especially in low flows periods will be lost directly to the sinks, but in higher flows water from Catchment G will flow overland to Catchment F.

This means that actual flows that the SSSI will receive from the Q3 outfall is likely to be a “hybrid” of the Catchment A and F line, lying closer to the prediction of Catchment F in lower flows and nearer the prediction for Catchment A in the higher flows. This “hybrid” is likely to be closer to the original pre-quarry catchment flows across the majority of flow conditions and certainly increased overall flows from conditions during quarrying activities when our analysis suggests that flows would be lower than pre-quarry conditions.

Figure 6-5: Sink hole catchments – modelled flows



7 Peak Flow Analysis

7.1 Introduction

This section considers the effect that the development will have on peak flows during storm events. The interim JBA report in July 2021 concluded that changes peak flow from the future Q3 outfall are of concern due to their potential to permanently alter the morphology of the SSSI (e.g. through scouring and erosion). Therefore, a model was require to evaluate flood flows and the attenuation affects provided by the large areas of standing water which will be incorporated into the future scheme

The nature of the pre quarrying the catchment compared to the proposed catchment, will change the way is generates quick flow in floods events in two main ways:

- The size of the catchment will increase which would increase the total flow,
- The catchment will/has changed from a steep narrow valley to a series of flat lakes. These lakes will have significant attenuation effects on flows.

These two factors potentially counter one another, with the first having the potential to increase peak flows, and the later reduce them. In this section estimations of pre-quarry flood events have been compared against modelled events passing through the site following development to assess how these factors might affect peak flows from the Q3 outfall.

Note – estimates of current peak flows have not been created. The current outfall arrange with a siphon outfall would make any estimate unreliable. The catchment size (Section 5) and low flows analysis (Section 6) suggests that the current smaller catchment (compared to the proposed and historic) combined with the attenuation effect of the Q3 quarry, has to current peak flows being significantly less than historic levels. This section therefore focuses on assessing if the proposed catchment will be able to restore the flashiness to the catchment, without creating flood events that cause geomorphological issues to the SSSI.

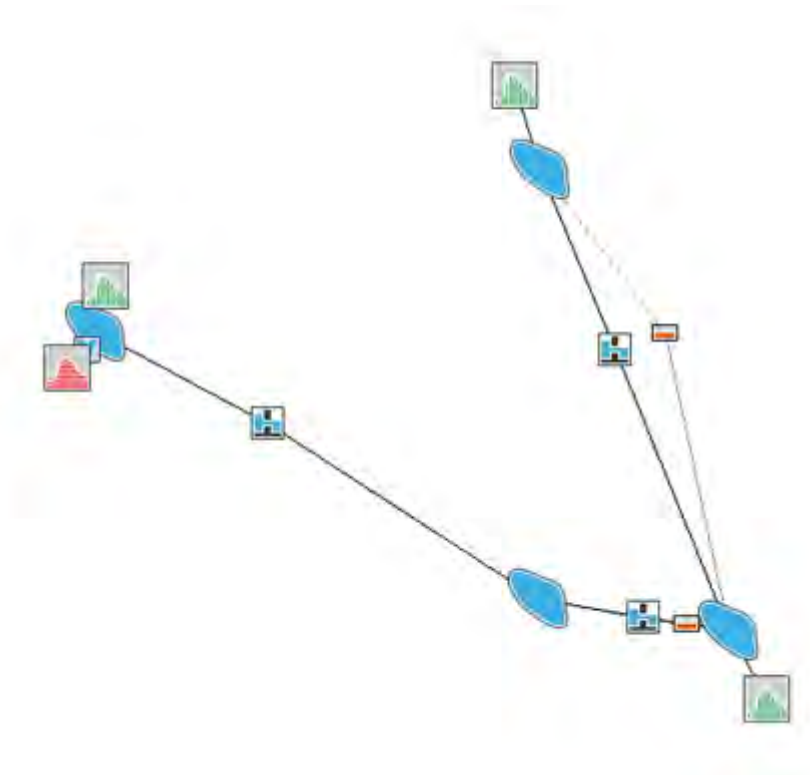
7.2 Pre-quarry estimations of flow

Pre-quarry estimation of flow during storm events were obtaining using the ReFH2 method based on the pre quarry catchments outlined in Figure 5-1. The 1 in 2, 1 in 10 and 1 in 100 rainfall events were derived for the catchment. It was established that a 2 hour event produced the critical (most flashy event).

7.3 Post-Development estimations of flow

Post-development estimations of flow were obtained through the construction of an 1D Flood Modeller model (see Appendix B for the technical model report). This estimated flow through the lagoons and ditch systems before discharging to the SSSI from the Q3 through a 0.6m wide open channel (see Section 8 for details of the outfall proposed).

Figure 7-1: Visual Representation of the Flood Modeller Model



7.4 Comparison of 2 hour rainfall duration events

Our flow analysis indicates that two hour rainfall duration events caused the greatest peak flows pre-quarrying. Figure 7-2 shows a series of hydrographs pre quarry and with the proposed catchments for a series of 2-hour events with different return periods. The following can be observed:

- The two-year return period peak pre quarry is estimated to be 0.15m³/s. The highest Low flow 2 flow estimate (Q0.1) is 0.12m³/s. The Q0.1 flow should be smaller than the two year return period event and therefore the predictions of two methodologies complement each other and are not contradictory.
- The peaks pre-quarrying were around 5 times higher than those which may occur following the proposed development catchment (see Table 7-1).
- Pre quarrying peaks occurred at around 2.5hours, with the proposed development scenario indicating peaking at around 7 hours.

Figure 7-2: 2 Hour Return Event Comparison

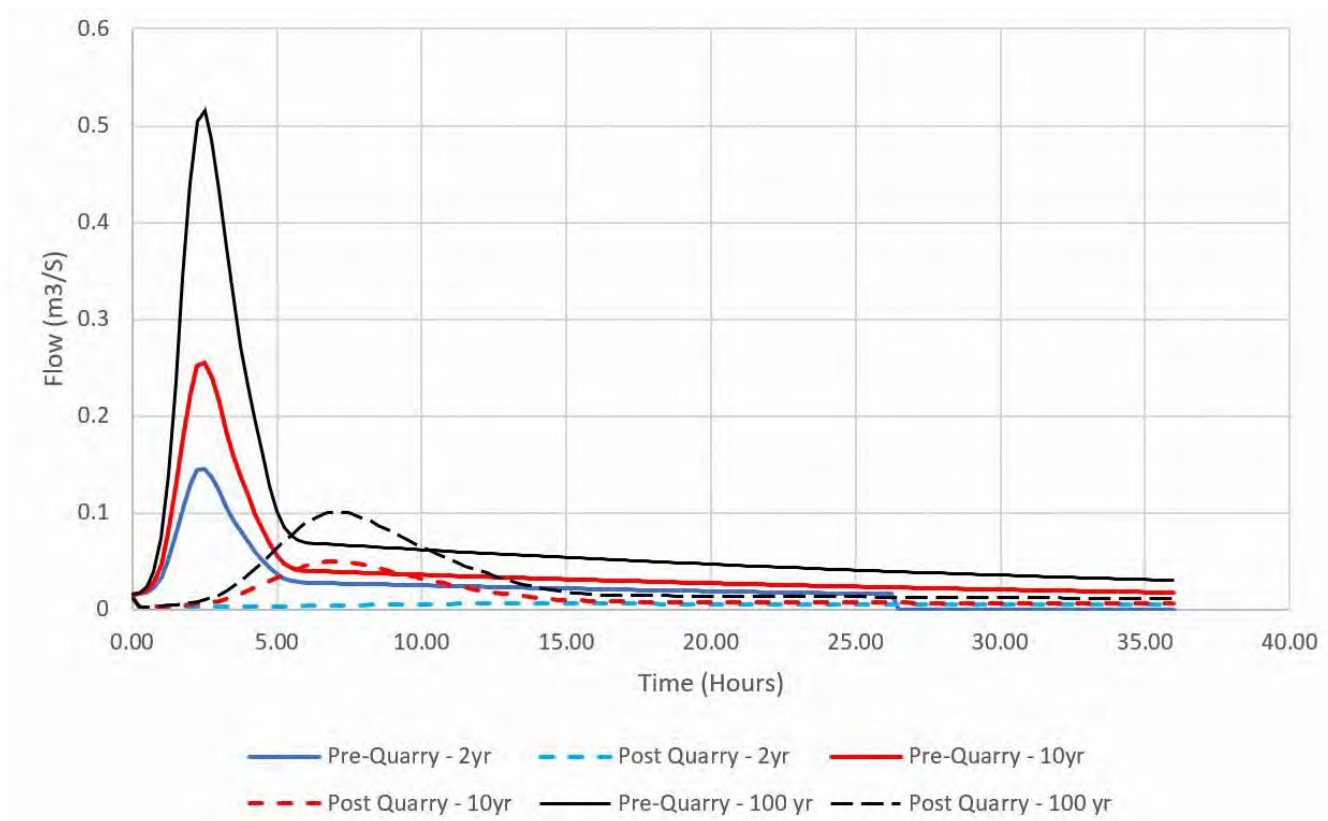


Table 7-1: Peak Flows for a 2 hour event Pre-quarry and with Proposed Catchment

Return Period	Pre-Quarry Flows (m ³ /s)	Proposed Catchment Flows (m ³ /s)
2	0.15	0.03
10	0.26	0.05
100	0.52	0.1

7.5 Comparison Against Critical Event Post Development

Due to the attenuating effects of the lakes in the post development scenario, longer rainfall events cause the greatest peak flows. Figure 7-3 and Table 7-2 compare the 2-hour pre quarry event with a 99 hour proposed catchment event (note 99 hours is the longest rainfall event ReFH can run). The events' peak flows are estimated to be around approximately 2 to 3 times greater pre-quarrying than post quarrying, which is significantly lower than the differences observed across 2-hour events. This means that while post development peak flows may not be as great as pre-quarrying peaks, there may be less difference than that shown within the 2-hour event analysis.

Figure 7-3: 2 hour Pre Quarry Events and 99 hour Proposed Catchment Events

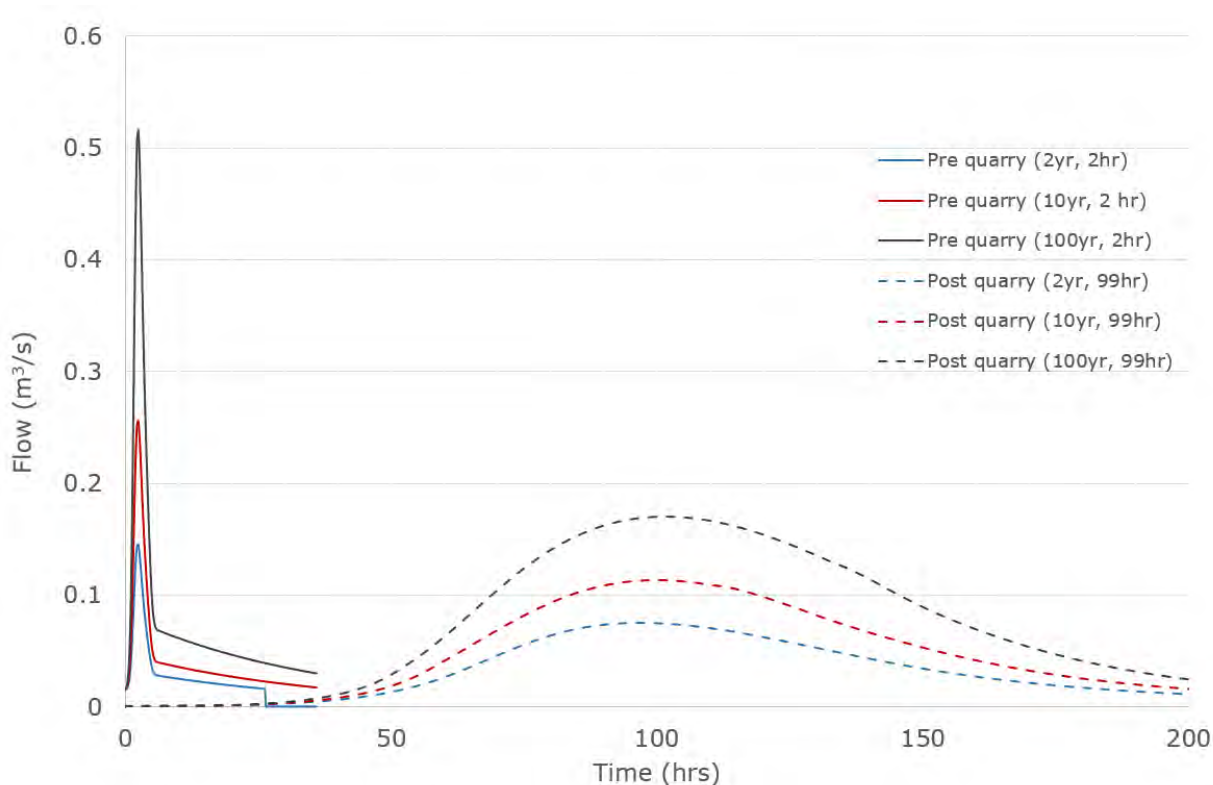


Table 7-2: Peak Flows for 2 hour Pre Quarry Events against 99 hour Proposed Events Catchment

Return Period	Pre-Quarry Flows (m ³ /s)	Proposed Catchment Flows (m ³ /s)
2	0.15	0.075
10	0.26	0.11
100	0.52	0.17

7.6 Alternative options

The Q3 lake clearly has a large attenuation effect on the flows discharging to the SSSI. The proposed permanent outfall channel from Q3 is currently being designed to be 0.6m wide and 0.5m deep (see Section 8.3) to broadly match the size and scale of the receiving watercourse. The outfall could be made larger increasing the maximum flow rate through the outfall, but this would potentially lead to increased disturbance to the SSSI.

7.7 Limitations and Caveats

The peak flow model has been developed solely to assess the flow changes and impacts on the SSSI and the results are based upon JBAs understanding of the outline drainage strategy for the site as currently proposed (and as described in the previous planning submission). If during the development of the detailed drainage strategy, there are

significant changes to the routing of flow through the site, or the levels of the lakes, the modelling may need to be re-evaluated. It should also be noted that the model has not been designed to cover Reservoir Act considerations. It is JBA's understanding that the recent construction of a spill way channel means that the Q3 lagoon no longer comes under the Act.

7.8 Summary of Peak Flow Analysis

The main concern before analysis was completed, was that the increase in catchment site would result in an increase in peak flows compared to the historic (pre-quarrying) situation. Peak flow modelling suggests that is highly unlikely. Therefore, based upon current drainage proposals the modelling results suggest a very low likelihood of more powerful and potentially damaging flows discharging into the SSSI from an outfall at Q3. Peak flows from the site into Stream A may be a third to half the size that they were before quarrying. Given the large-scale changes to peak flows that the Q3 lake and other elements of the quarry have historically created, there are limited options to modify the arrangement of the catchment to match peak flows to pre-quarrying conditions.

8 Q3 Outfall Design Considerations

This section summarises JBAs current understanding of the current and previous outfall arrangements and to identify the optimal outfall arrangement from the development into the SSSI in terms of seeking to replicate historic flows to the extent that this is possible.

8.1 Micro-catchment Changes with time

Prior to quarrying, two main sub-catchments drain to the point locations shown in Figure 8-1. However, following quarrying and the alteration of drainage paths, the two catchments have now become one. This is shown in Figure 8-2, which shows the current micro-catchment area down to the proposed outfall location. Figure 8-3 displays the catchment area to the proposed outfall following completion of the leisure development, which reflects the catchment changes discussed in Section 5.4.

Seepage areas, shown in Figure 8-4, may have been partly disrupted due to construction of the Q3 quarry, which lowered the water table within the sandstone. Currently, there are perched water tables above the main sandstone water table, which proceed to discharge at the seepage faces. Consequently, flows contributions from the seepages may be less than the pre-quarry environment.

Figure 8-1: Pre-quarry outfall micro-catchments

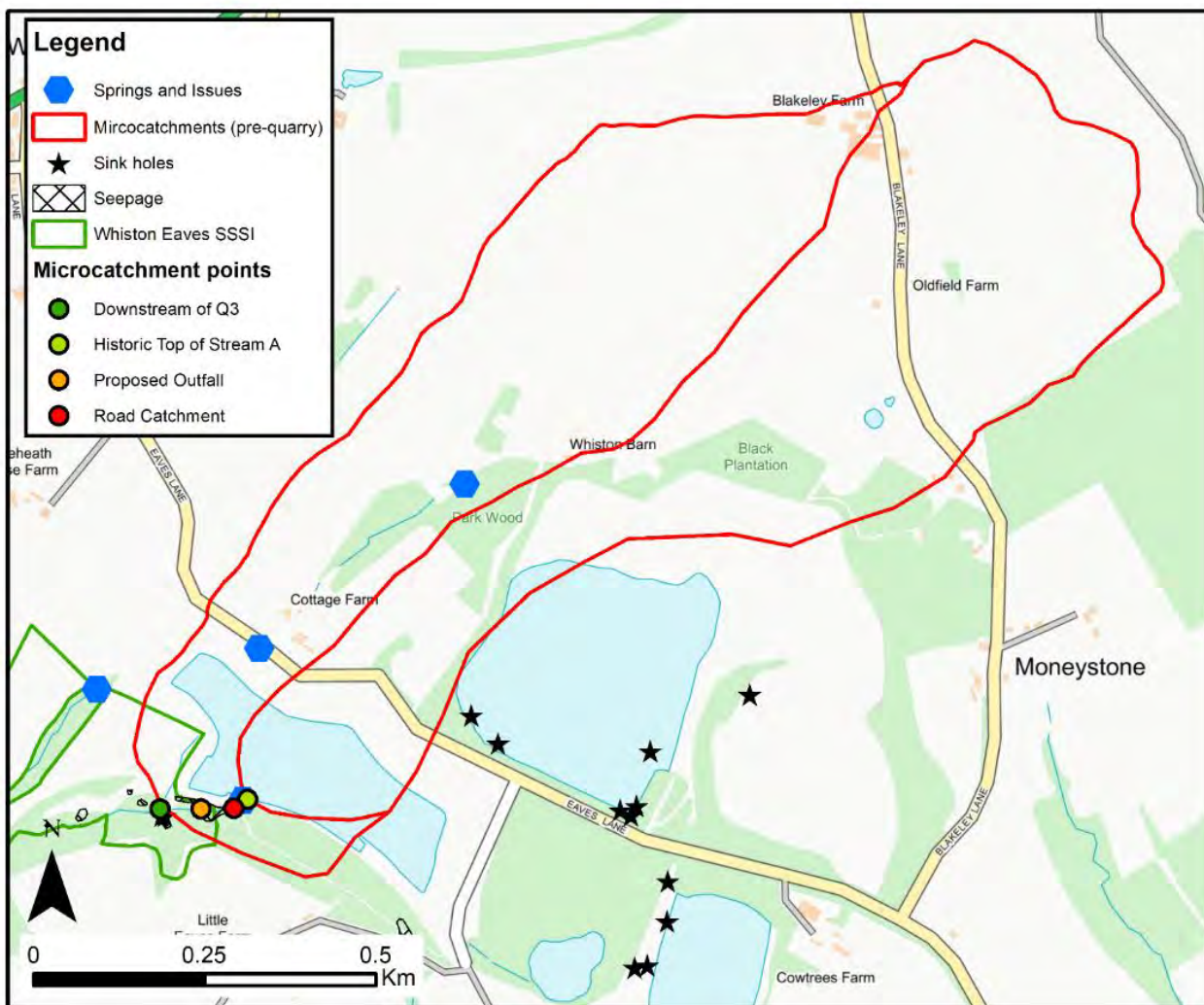


Figure 8-2: Current micro-catchments

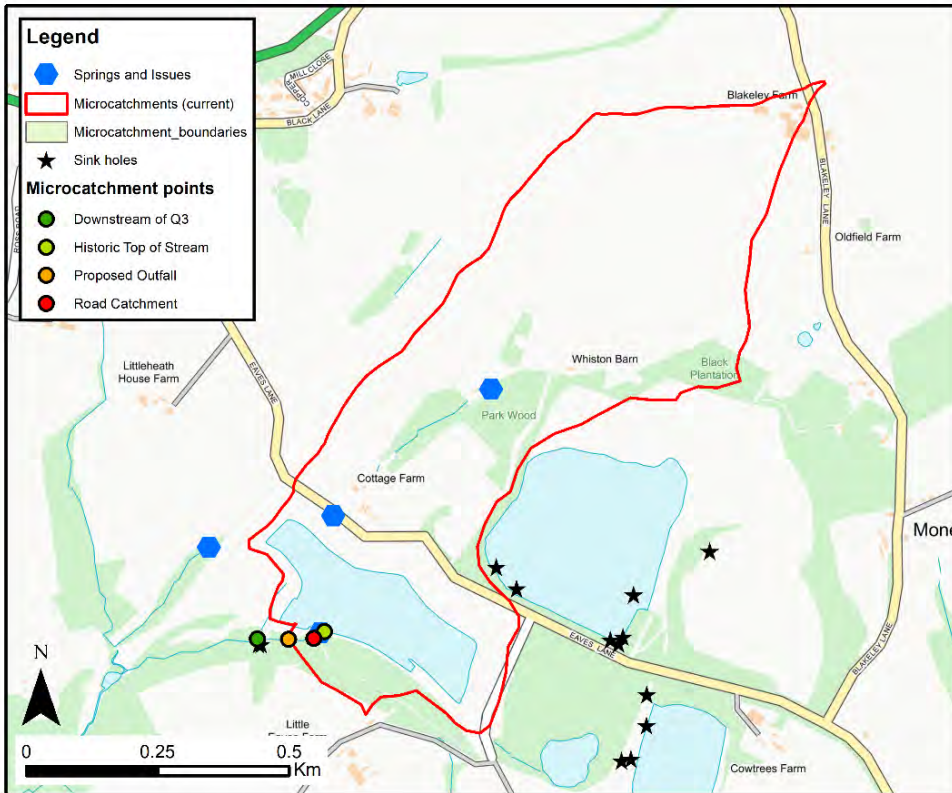


Figure 8-3: Proposed micro-catchment (post development)

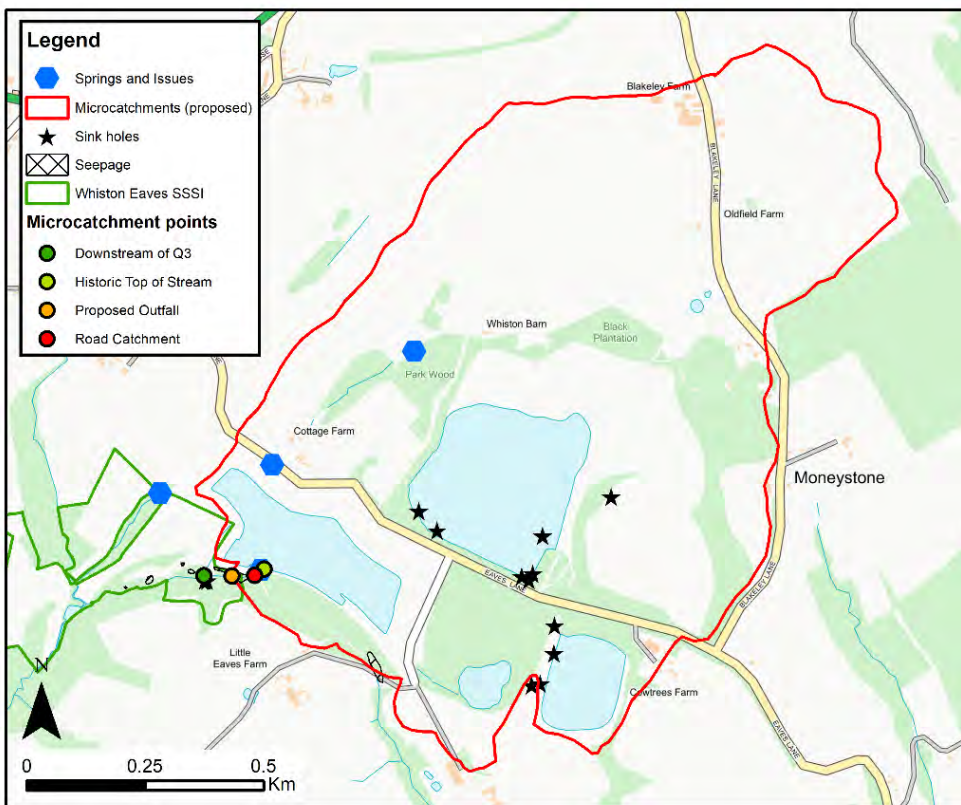
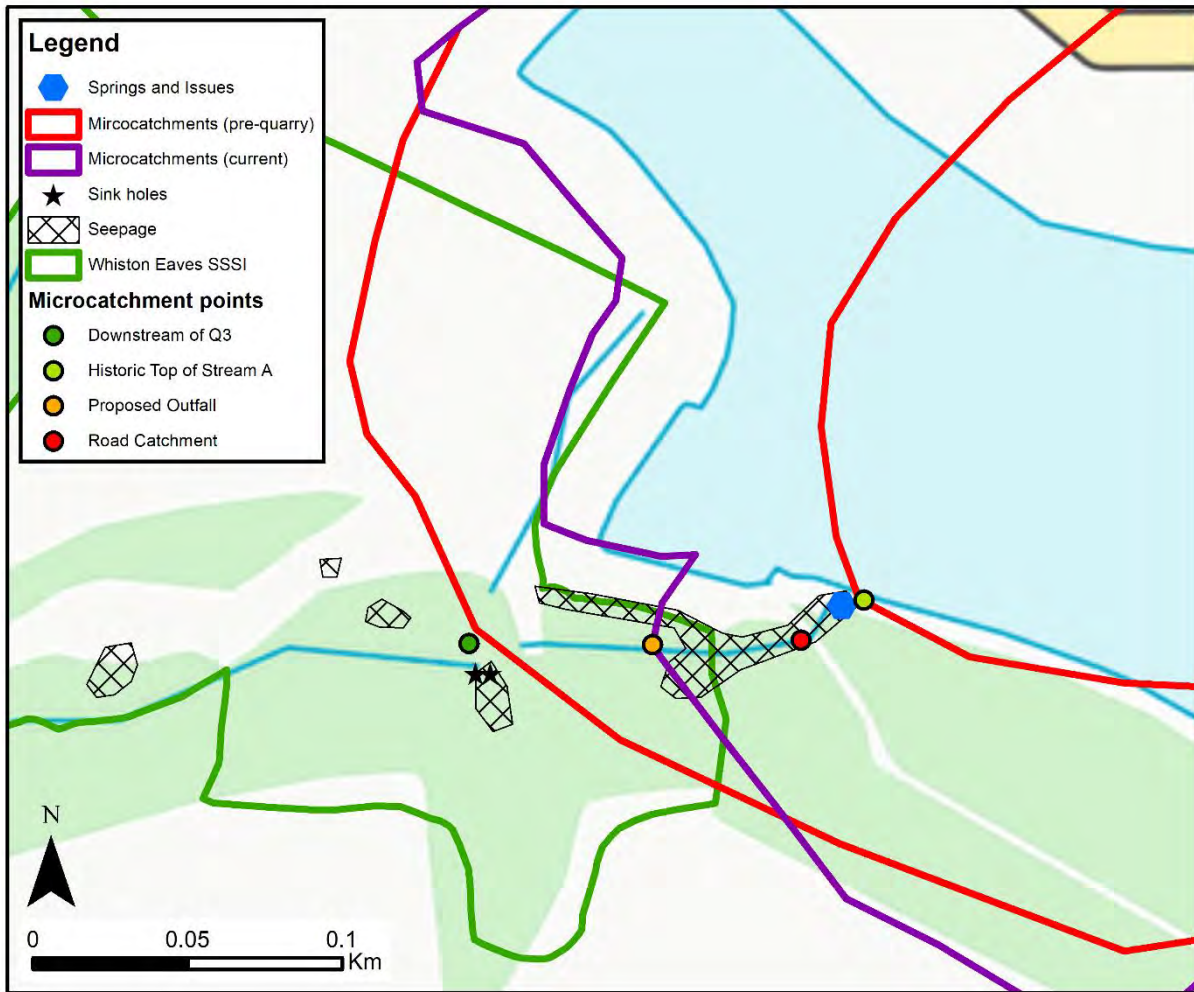


Figure 8-4: Seepages and micro-catchment changes



8.2 Current Outfall

Historic excavations into the ground surface have cut through a south-west flowing watercourse (referred to as Stream A throughout this report), resulting in the former quarry now being partially flooded (Q3 / Quarry C). A saddle sits at the south-west corner of the Q3 pond (Figure 8-5), which is the lowest point around the perimeter (at 158mAOD). If the water level in Q3 were to rise sufficiently, water would spill out from the south-west corner and into stream A, the existing watercourse downstream of the saddle.

However, a weir has previously been constructed at the saddle, comprising a 4.5m concrete wall with a 1.5m central wide section which acts as an overflow weir (Figure 8-6), and a 330mm diameter buried outlet pipe which sits on the downstream side (Figure 8-7). The pipe was designed to carry the outflow through the saddle and discharge into valley forming Stream A, if the weir was overflowing. In Summer 2021, the weir outfall was bypassed by a spillway channel set at 157.42m. This was designed so the risk of impounded water associated with Q3 lake were reduced as the lake would not classify as a reservoir under the Reservoir Act.

A siphon comprising two flexible hoses currently regulates the water level in the lake at around 156mAOD by discharging up to 800m³/day over the saddle and into Stream A. It is understood that the siphons are primed from a header tank next to the weir (Figure 8-5). Outside of large flood events the siphon forms the route that the surface water discharges through.

Figure 8-5: Natural Saddle, outfall structure and siphons – including header tank for priming siphons (adapted from Mott MacDonald (2021))



Figure 8-6: Outlet weir structure (adapted from Mott MacDonald (2021))



Figure 8-7: Outlet pipe (adapted from Mott MacDonald (2021))



8.3 Outfall redevelopment plans

The redevelopment of Moneystone Quarry as a leisure park requires the lake level of Q3/Quarry C to be lowered to 156mAOD. It is proposed that a new outlet channel is cut into the sandstone of the saddle, with the invert cut to the new lake level of 156mAOD.

The relocation of the outfall will in part offset the distribution to the seepages in the area because of the historic quarrying. The outfall will be located as far up the valley as the elevations will allow, to restore the flows to the extent that it is possible to the upper reaches of the SSSI. It will however not be possible to replicate the historic split of flows that the SSSI received. As partial mitigation for this a small catchment encompassing the development on the southern shore of Q3 will be directed into the top of the SSSI (see Figure 8-8).

Figure 8-8: Post leisure development micro-catchments (downstream extents)

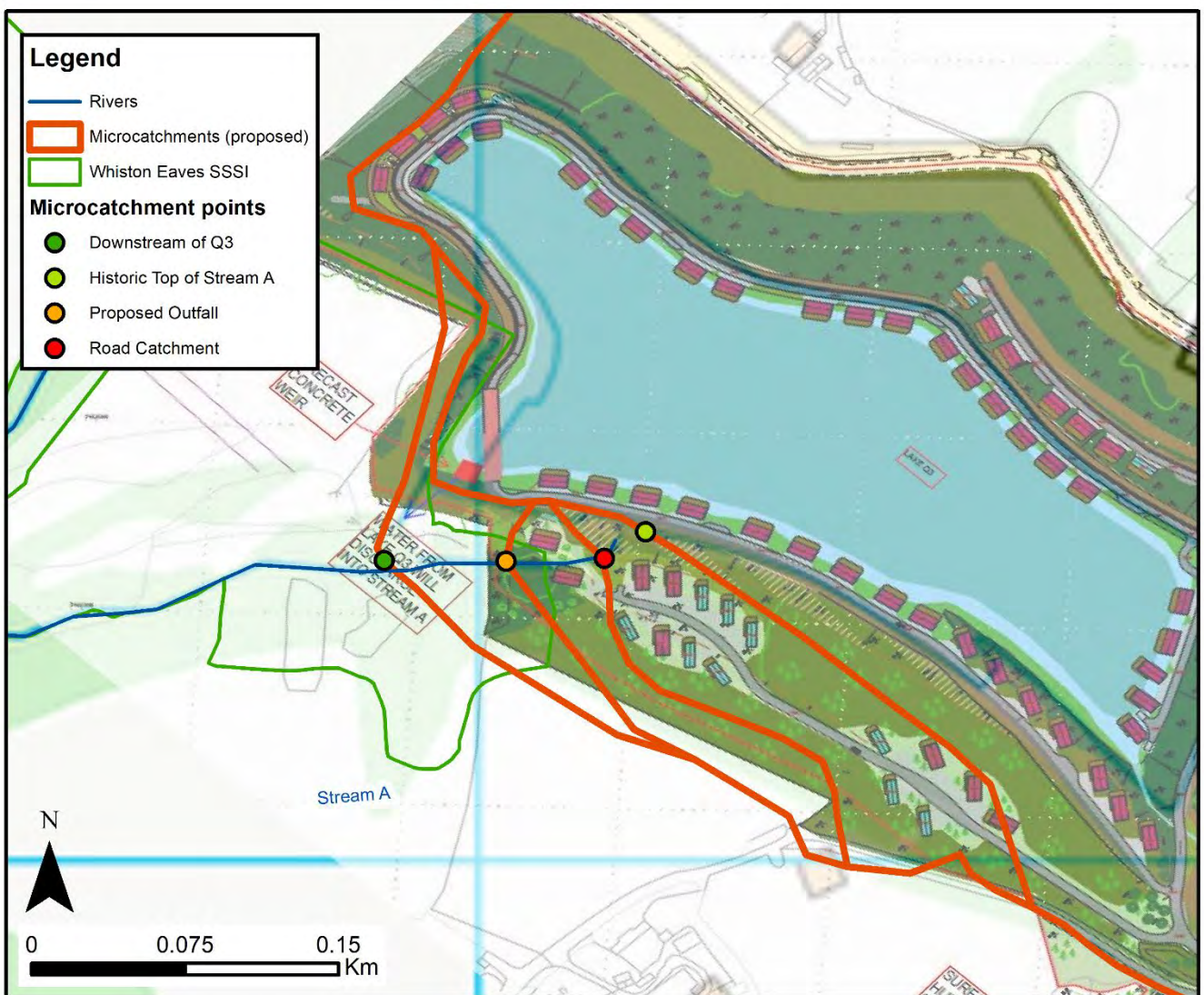


Figure 8-9 show a general arrangement for the proposed outfall. It has the following features:

- An outfall at 155.9mAOD.

9 Conclusions

The assessment has shown that catchments and surface water flows within the SSSI have changed over time in response to the development of the quarry.

A summary of our key findings are as follows:

- Comparison of modelled flows through the quarry which discharge into Stream A against actual monitored flow data from gauging points downstream of the SSSI show a good correlation. It is clear from our analysis of the pre-quarrying catchments that flows into the SSSI were typically approximately 25% greater historically than they are presently across a range of flow exceedances. This is due to a reduction in the catchment area and diversion of surface run-off through the quarry resulting from changing topography as the quarry developed.
- The current proposals involve routing the area defined as Catchment G immediately adjacent to Catchment F in this report via the Q3 lake and this leads overall to an increase of approximately 60% in the size of the catchment draining towards the SSSI relative to pre-quarry conditions.
- Within Catchment G there are numerous sinkholes which sit on the outcrop of the Rough Rock Sandstone. Groundwater monitoring data suggests that the sink holes provide a route for loss of surface water from the catchment which will eventually discharge to Stream D (and effectively by-pass Stream A) via a groundwater flow pathway.
- The net effect of sinkholes on flows to the SSSI if the current drainage proposals were to be implemented is that at low flows there would be an anticipated small increase in **flows which would in part “compensate” for the estimated 25%** reduction in flows in this range. At moderate to higher flows the impact of the sink holes will be more limited, with potential increased flows of between 50% to 60% relative to pre-quarrying conditions.
- Overall, plans to route the area identified as Catchment G has significant benefits for restoring the low flows resilience of Stream A towards to its historic pre-quarrying condition.
- Modelling indicates that peak flood flows down the SSSI catchment will have been significantly reduced by the changes in catchment shape, and the attenuating effect of the Q3. The current proposed drainage proposals with discharge from Q3 still result in attenuation of peak flows. Peak flows could be increased though increasing the size of the outfall channel, but this potentially will require increased excavation and disturbance within the SSSI, which should be avoided to the extent possible.
- The alternative to the current plans would be for the catchments to remain more or less as they are today (i.e. representing the conditions during quarrying). This would mean that low flow conditions to the SSSI would not be restored. In summary, diverting flow from Catchment G into the SSSI catchment would allow flows to more closely match historic flows across a range of return periods, especially at low flow and peak flood flows.
- The location of the outfall will not be able to restore the multiple flow discharge points to the SSSI as was potentially the most likely pre-quarry condition. However, the proposed outfall at the edge of the Q3 lake will allow flows to be restored near to the top of the SSSI. Therefore, the scheme as currently planned has the potential to enhance the ecohydrological conditions of the SSSI compared to the current situation.

A Appendices
A Relevant Correspondence



Thank you for your report shared with us on 23 February 2021, your ref: 418057HA.

1 Introduction

Laver Leisure is proposing to develop a leisure facility within the boundaries of the disused Moneystone Quarry, nr. Oakamoor, N. Staffs. As a part of this development it is proposed to construct an overspill outfall at the south-western tip of the Q3 lake into what has been termed "Stream A" which flows through the Whiston Eaves SSSI.

Regarding the proposed outfall, Natural England have concerns, relating to the integrity of the SSSI, about:

1. The rates of discharge from the outfall, and particularly higher and peak flows.
2. The design of the outfall, and specifically how it is proposed that the discharge from the outfall reaches the existing channel of Stream A within the SSSI.

Partly in response to these concerns Abbeydale BEC have produced a report entitled *Hydrological assessment of the proposed Q3 outfall at Moneystone Quarry, Oakamoor, Staffordshire* (ABEC, 2021). Some of the analysis within ABEC (2021) relies on information contained in a report entitled *Flood risk assessment report, Moneystone Park, Whiston, Staffordshire* (ABEC, 2014).

This document is a review of the above reports, in the context of Natural England's concerns about the proposed outfall. It comprises:

- Section 2; brief technical comments on ABEC (2014) in respect of the current context.
- Section 3; technical comments on ABEC (2021).
- Section 4; Natural England's views in relation to 1 above, in the light of ABEC (2014 and 2021).
- Section 5; Natural England's views in relation to 2 above, in the light of ABEC (2021).
- Section 6 provides summary conclusions.

2 Brief technical comments on ABEC (2014)

In the context of this review, the flood risk assessment provided in ABEC (2014):

- Refers almost exclusively to the proposed development as the receptor. That is, it assesses the risk of flooding for the development, rather than downstream areas, although the latter are referred to in general comments.
- Is wholly qualitative in its assessment, and doesn't predict specific return-period flood flows and levels. It refers to general processes, such as infiltration on vegetated surfaces, storage/attenuation in ponds and meandering streams, as examples of Sustainable Urban Drainage Systems (SUDS¹).

Importantly, the report provides surface water catchment areas which are used within the analyses in ABEC (2021). Catchment areas for the various lettered streams are provided for, 1) before the Q3 lake existed (Figure 5, ABEC [2014]), 2) the current condition (Figure 6), and 3) the proposed condition (Figure 7). Regarding these figures and the related calculated catchment areas:

- The delineation of some of the catchments is ambiguous with, for example; 1) the northern end of the catchment for Stream B, north-east of Whiston, being assigned to the catchment

¹ The relevance of SUDS in a largely non-urban setting is open to question.

for Stream C, and 2) the catchment boundary between Streams D and E passing through (at c. 90 degrees) Stream E.

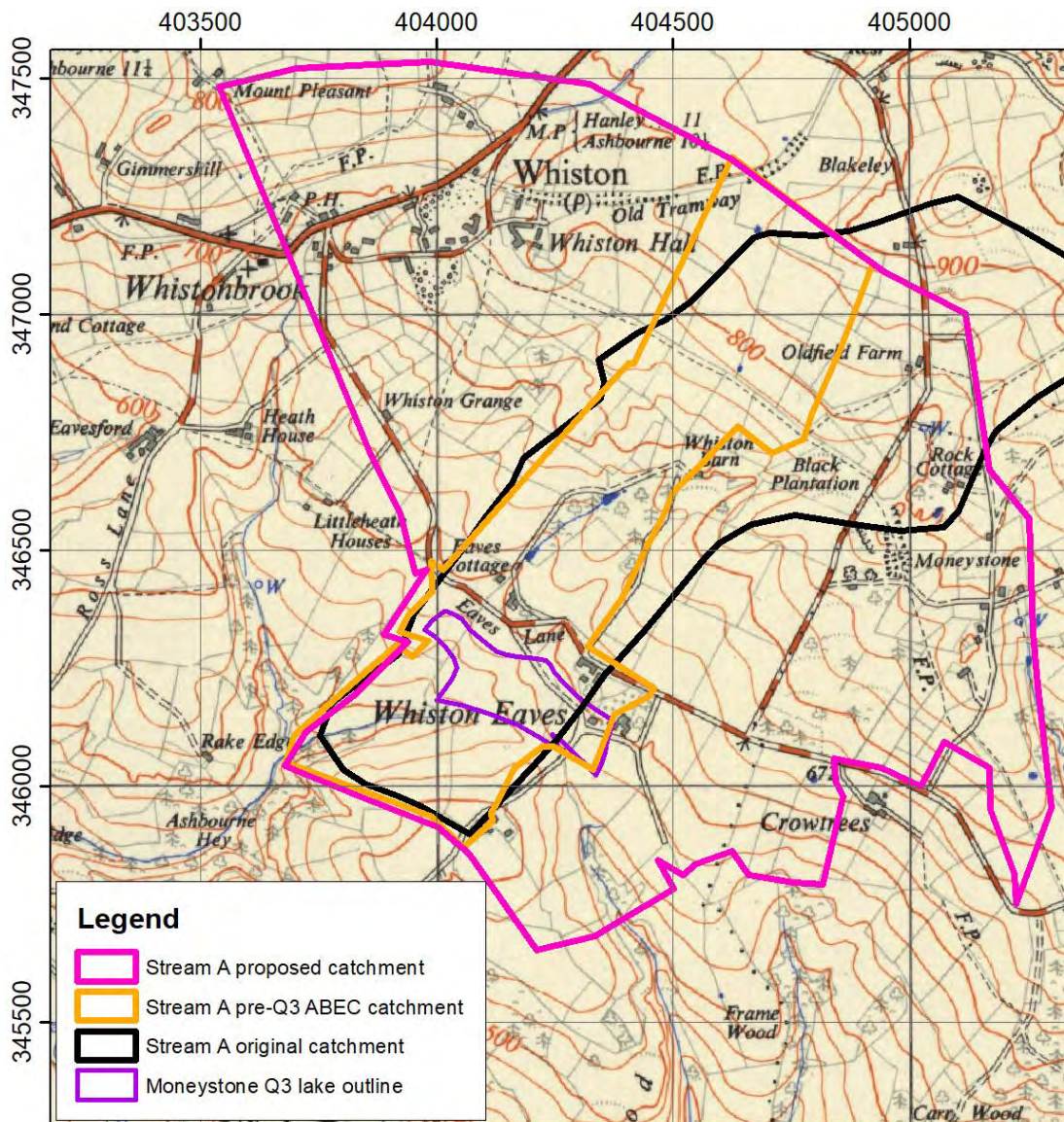


Figure 1. Various catchment areas for Stream A, projected over the OS 1:25,000-scale survey.

- The pre-Q3 catchment for Stream A is shown in Figure 5 (ABEC, 2014), and reproduced² in Figure 1 here. The area is given in a table in Section 7 (ABEC, 2014) as 560,400 m², this figure is within 0.5% of the area digitised for Figure 1.
- The proposed catchment for Stream A is shown in Figure 7 (ABEC, 2014), and reproduced in Figure 1 here. The area is given as 1,624,700 m², and Figure 7 shows that the increase in area from the pre-Q3 catchment is caused primarily by the capture of larger parts of the catchments of streams to the north-west (Stream C) and south-east (Stream D). It is, however, worth noting that the corresponding area digitised for Figure 1 is 2,135,201 m², which is 510,501 m² (31.4%) larger than the area measurement given in ABEC (2014).

The report concludes that “although the proposals will increase the catchment area to Stream A, the attenuation proposals will significantly reduce the peak flows to the stream”. Using the catchment areas given within the report, it is proposed to increase the catchment area of Stream A from 560,400 m² to 1,624,700 m², an increase of 190%; i.e. the catchment would be almost

² Figure 5 was copied and geo-referenced in GIS before the catchment was re-digitised for presentation here.

three-times the original area. Given this very significant increase in area, the statement that “attenuation proposals will significantly reduce the peak flows to the stream” is difficult to accept.

3 Technical comments on ABEC (2021)

Section titles relate to those in ABEC (2021).

Section 3

It is claimed that accumulation of stones on the slope below the proposed outfall is “a stone delta formed by the now dry northern tributary”. The map reference for the outfall is given (in Section 1 of ABEC [2021]) as 403996 346161, and this accords with the known locations of boreholes and related infrastructure. It is important to note however that the northern tributary, which is still marked on the OS 1:25,000-scale survey, crossed the east-west fenceline at the top of the slope at 403952 346175; this is at least 40 m west of the proposed outfall, and therefore it is extremely unlikely that the accumulation of stones is a fluvial feature related to the northern tributary.

Section 5

Elevations (maOD) relating to the trial pits (e.g. top, base) would be useful, so that they can be compared with other features.

The report states that “no groundwater was encountered during the course of the trial pitting”. Does this mean that there was no flowing groundwater, or that the side of the trial pits didn’t appear to be saturated? There is no comment as to how this observation fits within the overall hydro(geo)logical conceptual model for this area.

Under Bullet I), the statements that there was “no observed drawdown during the period observed” in TPS1, but that “several seepages and small flows were occurring from the lower banking within the SSSI directly to the south and west of the pit” appear to be contradictory. (A similar observation is made under Bullet V)).

Also under Bullet I), the hydraulic conductivity of the sandstone in TPS2 was calculated to be 7.7×10^{-6} m/s; this equates to c. 0.7 m/d, which isn’t particularly low (very approximately that of a fine sand), and the larger-scale hydraulic conductivity for the sandstone would be expected to be higher than measured at a relatively small scale in the trial pit, for a unit in which fracture flow is dominant.

The report refers to an “area of sinkholes 8-10 m downstream” of where overflowing water from the trial pits joined Steam A. These sinkholes were not observed or discussed during the field visit (December 2020), and it is unclear how their presence and operation fits within the overall hydro(geo)logical conceptual model for this area.

Section 6

It is claimed that “as identified in the flood risk report, whilst the surface water catchment passing through Stream A will be returned to an area of 1,624,700 m², peak flows will be limited by the use of swales and increased vegetation within the park together with a series of lakes so attenuating peak flows”. Actually, as noted above, the table in Section 7 of ABEC (2014) notes that the original catchment area for Stream A was estimated at 560,400 m², so the proposed catchment area is almost three-times larger than the original catchment. There is also no indication of the anticipated (quantitative) degree to which natural flood management (NFM) measures will reduce peak flows in Stream A.

The meaning of the sentence “surface flow will also be severely limited by the sinkholes and groundwater flow through the Rough Rock sandstone which has been significantly increased in the area of Q3 where fracture flows currently maintain lake levels below the level of the quarry outfall set at 159m AOD” is not clear, and it has therefore been discounted from this review.

Section 8

It is claimed that “due to the many partly known variables present in this situation detailed finite element modelling is considered unlikely to provide a reliable estimate of future flows through Stream A”.

The rainfall data given in paragraph 3 appears to be incorrect as the site clearly doesn't receive an average rainfall of 77 mm/d; it is thought likely that the correct unit for the figures is mm/month.

The empirically-based flow estimation for the Q3 outfall is difficult to follow, and again seems to rely on a qualitative assumption that flows will be reduced by within-development NFM measures.

Considering the above in relation to Section 8, Natural England would like the opinion of a qualified and practicing hydrologist on what the best method would be to estimate peak flows for Stream A, for an agreed return period event in this context.

Section 9

It is proposed to re-position the syphon discharge higher up Stream A, which it is said "would be particularly beneficial where the flow was seen to drain into the sinkholes in the stream floor". Since Natural England has not seen the sinkholes, and is unaware of how their presence and operation fits within the overall hydro(geo)logical conceptual model for this area, it is impossible to comment on this proposal.

4 Natural England's view on the predicted rates of discharge from the Q3 outfall

Prediction of future flow rates into Stream A within ABEC (2021) is based on an empirical approach, using historical stream discharge data as a general model for future behaviour, with adjustments according to changes in circumstance between the pre-Q3 lake and proposed future catchments.

A fundamental aspect of such an empirical approach to flow estimation is agreement and consistency on the catchment areas involved. Four catchment areas can be considered for Stream A, to the gauging station within the SSSI:

1. The pre-quarrying catchment. For this review, this catchment has been estimated using the contours displayed on the OS 1:25,000-scale mapping from 1951; the catchment is included in Figure 1, and has an area of 862,556 m².
2. Pre-Q3 (quarry and lake) catchment. This is delineated in ABEC (2014)(reproduced in Figure 1), and has an area of 560,400 m². It is smaller than 1 above, primarily because some of the upper part of the catchment was captured by the quarry workings to the north of Whiston Eaves Lane.
3. The proposed catchment (ABEC measurement). This is delineated in ABEC (2014)(reproduced in Figure 1), in which it is stated to have an area of 1,624,700 m².
4. The proposed catchment (NE measurement). The area of the mapped catchment for 3. above has been measured as 2,135,201 m² for the current review.

Considering the above, there would appear to be no justification for the statement "the catchment is to be returned to the pre-quarrying area of 1,624,700 m²" (ABEC, 2021, Section 8, 1st paragraph). Table 1 expresses the proposed catchment areas (3 and 4 above) in terms of multiples of the pre-quarrying or pre-Q3 catchment areas (1 and 2 above).

The figures in Table 1 show that the proposed catchment is between 1.9- and 3.8-times larger than the pre-quarrying or pre-Q3 catchment areas. It seems very clear, therefore, that whichever figures are used the proposed catchment area represents a significant increase from the pre-quarrying or pre-Q3 catchment areas; this was previously acknowledged in ABEC (2014). It would therefore appear that much more water will be flowing down Stream A within the SSSI than was the case pre-quarrying, or pre-Q3.

Table 1. Proposed Stream A catchment area expressed as multiples of pre-quarrying and pre-Q3 catchment areas.

		Proposed (ABEC, 2014)	Proposed (NE)
	Area	1,624,700 m ²	2,135,201 m ²
Pre-quarrying	862,556 m ²	1.9x	2.5x
Pre-Q3	560,400 m ²	2.9x	3.8x

It should also be noted in relation to ABEC (2021) that:

- No attempt has been made at a rainfall event return-period analysis, and related calculation of peak flows in Stream A; the analysis appears to relate solely to the general flow duration curve. Under the constraints of the empirical approach, it would be useful to identify specific rainfall events, assess their return-period, and then analyse the resulting flow measurements in Stream A.
- The description of the attenuation effects of lengthened flowpaths and quarry lakes are semi-quantitative (e.g. flowpath lengths, lake areas), with some estimation of how long it takes for the lakes to reach peak levels, or to rise. There is no detailed quantitative assessment of the flow attenuation effects of the extended flowpaths and lakes, and there is no consideration of how attenuation would be reduced if a significant rainfall event occurred after a prolonged wet period.

5 Natural England's view on the design of the outfall

Detailed consideration of the location and design of a Q3 quarry outfall is dependent on a clear and agreed understanding of the predicted discharge profile and, given the contents of Section 4 above, such an agreement does not exist at present.

To facilitate further consideration, a clearer description of the morphology and function of the sink holes in the bed of Stream A, how the function fits within the wider hydro(geo)logical conceptual model, and the effect of the sink holes of the discharge of Stream A, is required.

It is worth noting that the accumulation of stones down the bank adjacent to the proposed outfall do not appear to be related to the now-dry northern tributary of Stream A, since the latter was located around 40 m west. The stones are therefore almost certainly not a "delta", and are perhaps more likely to be the remnants of a dry-stone wall.

Once the above are fulfilled, a detailed consideration of the location and design of a Q3 quarry outfall should take the form of a cost-benefit analysis of the available options, including the currently proposed outfall and an outfall which discharges to Stream A where its channel meets the boundary of the quarry (i.e. higher upstream).

6 Conclusions

The method for estimating flows in Stream A.

It is stated in ABEC (2021) that "due to the many partly known variables present in this situation detailed finite element modelling is considered unlikely to provide a reliable estimate of future flows through Stream A". Natural England requests the opinion of a qualified and practicing hydrologist on what the best method would be to estimate peak flows for the revised Stream A, for an agreed return period event in this regard, and how they would compare with pre-quarrying flows.

Should an alternative method be advised as more appropriate, it should be used. If not, the following conclusions apply if the empirically-based approach is retained.

The empirically-based flow estimation within ABEC (2021)

As demonstrated above, there would appear to be no justification for the statement "the catchment is to be returned to the pre-quarrying area of 1,624,700 m²" (ABEC, 2021, Section 8, 1st paragraph), and indeed this appears to contradict ABEC (2014) which notes that the catchment area will increase from 560,400 m² to 1,624,700 m².

It is demonstrated above that the proposed catchment for Stream A is between 1.9- and 3.8-times larger than the pre-quarrying or pre-Q3 lake catchment areas. This is a significant increase in catchment area, which means that much more water will be flowing down Stream A within the SSSI than was the case pre-quarrying, or pre-Q3 lake.

Natural England requests that clarity is provided on the derivation and relevance of the various catchment areas for Stream A (see Section 4), with a view to reaching agreement on this issue.

Natural England also requires:

- Rainfall event return-period and peak flow analysis, using the observed rainfall and stream flow dataset. Appropriate factors for the effects of climate change should be applied.
- Quantitative assessment of the flow attenuation effects of the extended flowpaths and lakes within the quarry, and consideration of how attenuation would be reduced if a significant rainfall event occurred after a prolonged wet period.

The design of the outfall

Detailed consideration of the location and design of a Q3 quarry outfall is dependent on a clear and agreed understanding of the predicted discharge profile; this does not exist at present.

A clearer description of the morphology and function of the sink holes in the bed of Stream A, how this function fits within the wider hydro(geo)logical conceptual model, and the effect of the sink holes of the discharge of Stream A, is required.

A detailed consideration of the location and design of a Q3 quarry outfall should take the form of a cost-benefit analysis of the available options.

References

ABEC, 2014. Flood Risk Assessment Report. Moneystone Park, Whiston, Staffordshire. Report 418040FR, October, 2014.

ABEC, 2021. Hydrological assessment of proposed Q3 Outfall at Moneystone Quarry, Oakamoor, Staffordshire. Report 418057, February 2021.

Natural England, 16 April 2021.

B Modelling Report

Moneystone Quarry Hydraulic Modelling Report

FINAL Report

November 2021

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Contract

This report describes work commissioned by Bolsterstone Group plc, by an email dated 27/04/2021. Katherine Dixon and Kevin Haseldine of JBA Consulting carried out this work.

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Purpose

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Executive summary

JBA Consulting have been commissioned by Laver Leisure (Oakamoor) Ltd to assess the hydrological impact of proposed drainage arrangement changes on the neighbouring Whiston Eaves Site of Special Scientific Interest (SSSI). The proposed drainage changes are part of a wider development scheme for a proposed leisure development for which planning permission has been granted subject to conditions.

It is proposed to route surface water drainage from the site through an outfall point near to an existing quarry void known as Q3 through an adjacent area of land which forms a SSSI. Natural England has raised concerns in relation to the discharge proposals and potential impacts upon the SSSI.

The hydraulic modelling shows the effect of the extensive lake system is to lower the peak flows and extend the hydrographs. Pre-quarrying flow estimations were obtained from ReFH2.3 and indicated that the peaks occurred at around 2.5-hours, whereas the post-quarry peaks occurred at around 7-hours. The pre- and post-quarry scenario flows were also produced for the 99-hour storm event, critical only for the post-quarry event. The pre-quarrying peaks occurred at around 50-hours with the post-quarry peaks occurring at around 350-hours.

It can be concluded that the peak flows down the SSSI catchment will lower post development than they were historically due to changes in catchment shape and the attenuating effect of the lakes.

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Abbreviations

1D	One Dimensional
CSD	Critical Storm Duration
FEH	Flood Estimation Handbook
LIDAR	Light Detection and Ranging
ReFH2	Revitalised Flood Hydrograph
SSSI	Site of specific interest

1 Introduction

1.1 Project Overview

JBA Consulting was commissioned by Laver Leisure (Oakamoor) Ltd to assess the hydrological impact of proposed drainage arrangement changes on the neighbouring Whiston Eaves Site of Special Scientific Interest (SSSI). The proposed drainage changes are part of a wider development scheme for a proposed leisure development for which planning permission has been granted subject to conditions.

It is proposed to route surface water drainage from the site through an outfall point near to an existing quarry void known as Q3 through an adjacent area of land which forms a SSSI.

Natural England have communicated their concerns through the planning process. One concern relates to the future discharge profile compared to the original pre-quarrying condition. This was further clarified during a site meeting on 11 May 2021. Specifically, it was requested an additional assessment of the likely average and peak flows from the site at the outfall and how these flows might compare against pre-quarrying conditions.

1.2 Site Overview

The Moneystone Quarry development site is located approximately 1km south-east of the village of Whiston in northern Staffordshire, centred at National Grid Reference SK 04553 46124. After the cessation of quarrying in December 2010, the site comprises a series of ponds surrounded by a mixture of wetlands, grassland, woodland and shrubland. Whiston Eaves SSSI is located approximately 300m southwest of Q3, which is the largest pond within the former quarry. The post-quarry seeks to incorporate a new leisure park development which will result in the generation of three attenuation lakes where water will flow westwards from L4 → L5 → Q3, through a network of open channels, as shown in Figure 1.1.

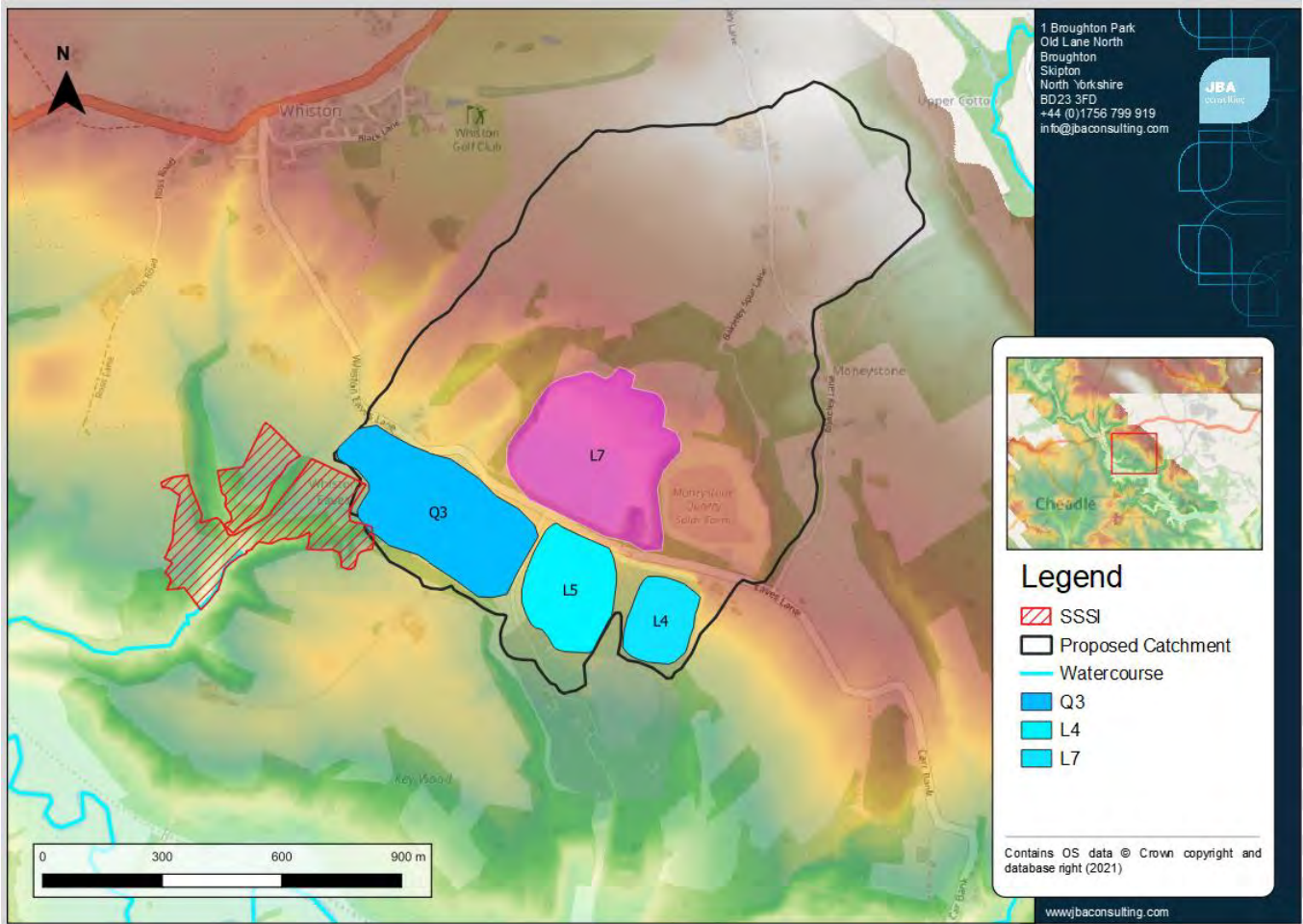


Figure 1.1: Map showing the post-quarry catchment

Several unnamed tributaries of the River Churnet flow through the Moneystone Quarry development site area, predominantly in a south-east direction. As shown in Figure 1.2, the catchment boundaries for these streams have changed over time due to the changing nature of the ground surface during quarrying, hence altering the surface water drainage paths. In order to understand how the catchment boundaries have changed, it is necessary to explore the catchment boundaries at various points in time: pre-quarry (pre-1957) and proposed catchments following completion of the new leisure development.

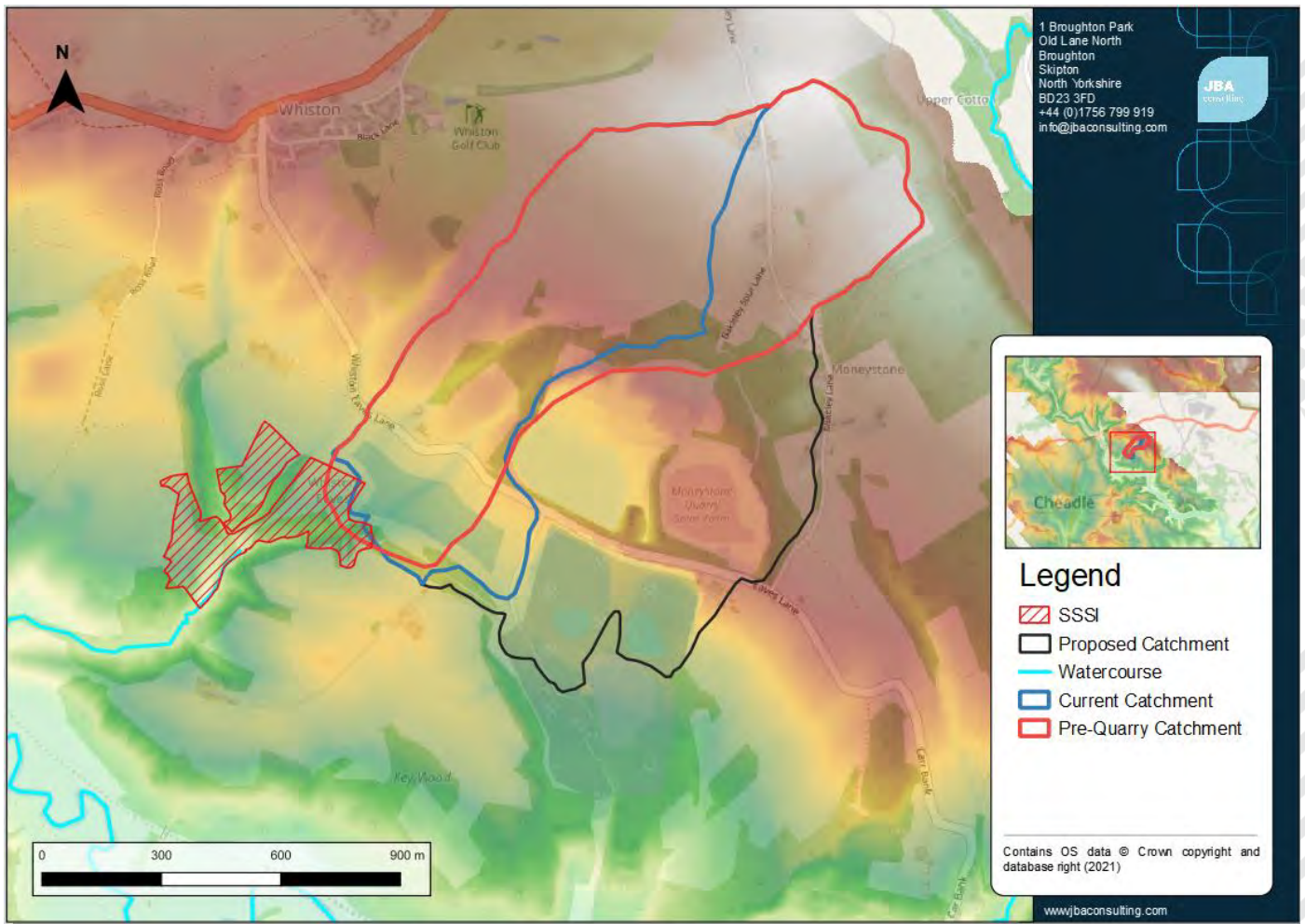


Figure 1.2: Map showing the changes in catchment size and shape overtime

2 Input data

This section of the report outlines the data available with which to construct and update the hydrological and hydraulic modelling.

2.1 Topographic data

The following topographic survey datasets were made available for the current project:

- 29644_T_REV 1.dwg – Topographic survey data carried out by Greenhatch Group in March 2018

2.2 LIDAR

The following Light Detection and Ranging (LIDAR) data was available for use on this project:

- 2019 2m resolution LIDAR.

2.3 Development plans

The following development plans were made available for the current project:

- 'Drainage stratp2.pdf' – Drainage strategy carried out by JPG in October 2019
- 'Surface water GA notes.pdf' – Detailed water levels based on discussion between Alexander Jones (JBA Consulting) and Peter Lloyd (Abbeydale BEC) on the 23 August 2021.



Figure 2.1: Proposed drainage strategy for Moneystone

3 Model approach and justification

The hydraulic modelling approaches adopted for this project are summarised in the following chapter.

3.1 Hydrological modelling

The hydrological approach adopted for the Moneystone Quarry model used flow estimates generated from the Revitalised Flood Hydrograph (ReFH) 2.3 software. This approach allows the generation of design hydrographs for rural ungauged catchments and includes estimation of hydrograph volume (unlike Flood Estimation Handbook (FEH) Statistical) which is essential for estimating flood flows in a system with a pond / lake network. Appendix A: FEH calculation record details the full FEH calculation record.

Given the lack of lake network in the pre-quarrying scenario, ReFH 2.3 alone will be used to estimate flows in this scenario, with no requirement to route these through a hydraulic model.

3.2 Hydraulic modelling

The post-quarry scenario for Moneystone Quarry was represented as a one-dimensional (1D) Flood Modeller hydraulic model. Key hydraulic structures included in this model were:

- Existing attenuation lakes,
- Moneystone Quarry,
- Starting water levels,
- Orifice units to represent the movement of water throughout the system from Moneystone Quarry and the attenuation lakes,
- Downstream spill from Q3,
- Tunnel from existing quarry,
- Spill heights.

Overview of Flood Modeller model	
1D domain	Flood Modeller - 4.6
Model name:	Moneystone Quarry
Survey	Topographic survey provided by Greenhatch Group in March 2018.
Upstream boundaries:	The proposed catchment was split into three sub-catchments based on the LIDAR data. The inflows are applied to each of the boundaries shown in Figure 3.1 below as flow-time (QT) units.

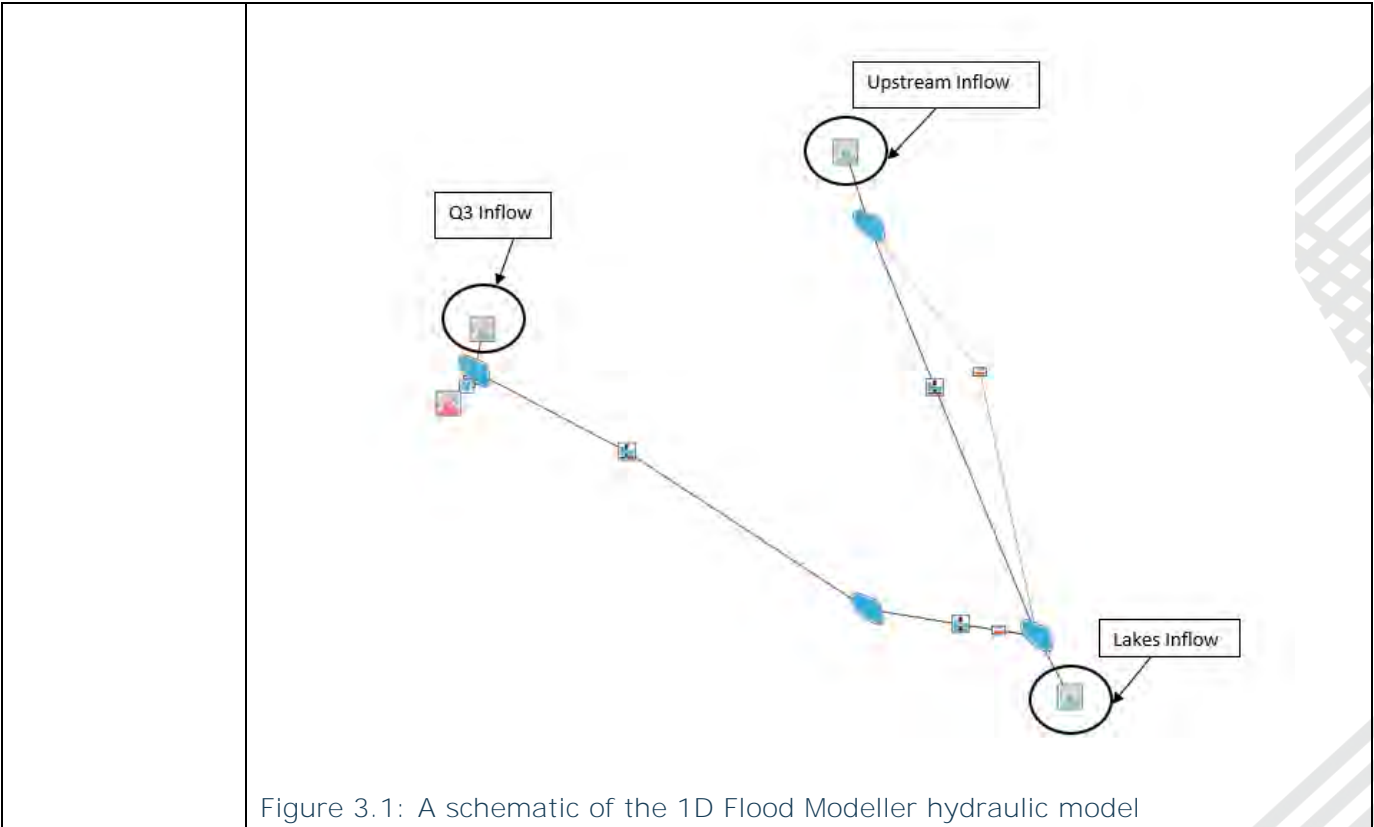
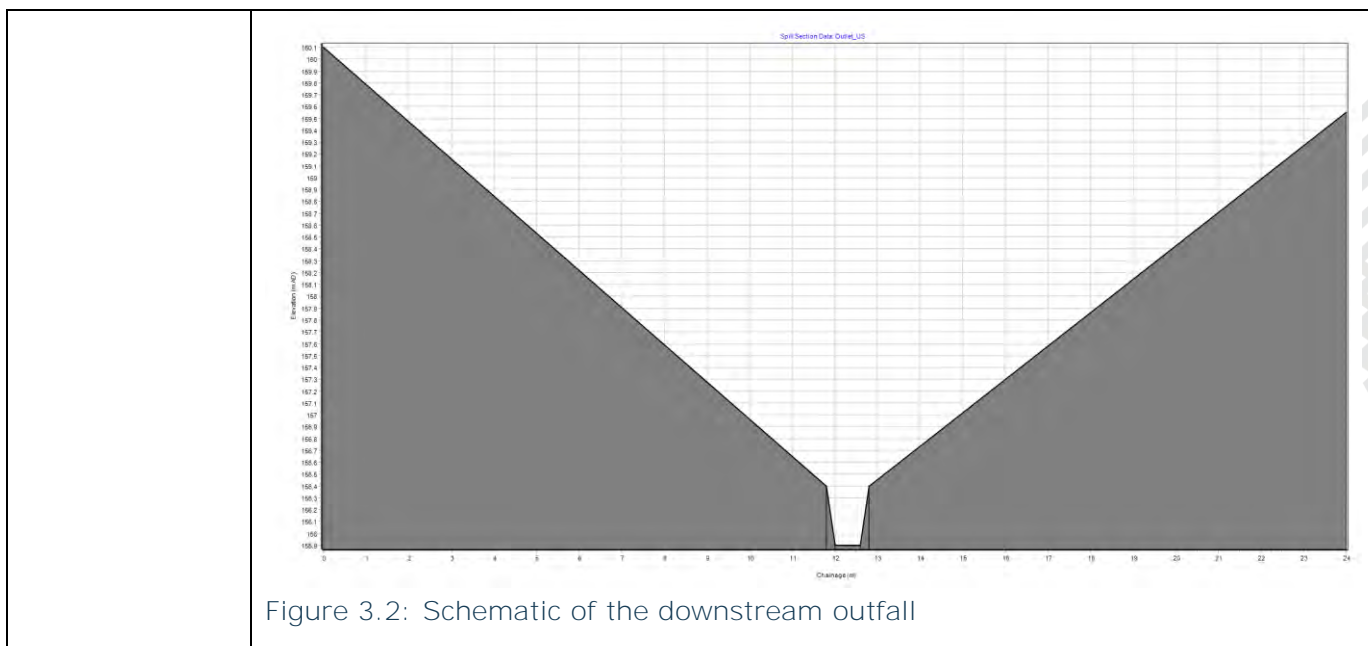


Figure 3.1: A schematic of the 1D Flood Modeller hydraulic model

Downstream boundaries:	A downstream boundary was placed on the watercourse, 45m downstream of the spill leaving Q3. This was modelled as a level-time (HT) unit, using 150mAOD as constant level value.
Moneystone Quarry	Moneystone Quarry was generated using LIDAR, topographic survey and the reservoir generator tool in Flood Modeller. This provided a volume elevation curve. The starting water levels of the quarry was amended to reflect lake levels as defined in the 'surface water GA notes.pdf'
Attenuation Lakes	The attenuation lakes were generated using LIDAR, topographic survey and the reservoir generator tool in Flood Modeller. This provided an area - elevation curve. The starting water levels of each lakes match those as defined in the 'surface water GA notes.pdf'
Tunnel from Moneystone quarry	The tunnel from Moneystone Quarry has been represented using an orifice unit. The invert level of this tunnel was taken from levels defined in the '29644_T_REV 1.dwg'
Orifice Units	Orifice units were used to represent the structures between each lake. Dimensions from these were taken from 'surface water GA notes.pdf'.
New Downstream Outfall	The new downstream outfall was modelled using a spill unit. This represents the proposed outfall with a crest of 155.9mAOD, 0.6m wide and 0.5m deep.



3.2.1 Design runs

The model was run for the following return periods: 2-year, 10-year, and 100-year. The results of these design runs are discussed in Section 4.

3.3 Sensitivity tests

Due to the association between the attenuation lakes and adjoining spills, it was deemed appropriate to test the sensitivity of these structures to assess any potential impact on the flow downstream of Q3 leading into the SSSI.

The following sensitivity test was undertaken and applied to the 100-year return period.

- $\pm 20\%$ change to structure coefficients

3.4 Critical Storm Duration

Pre-quarry estimation of flow during storm events were obtained using the ReFH2.3 method alone. The critical duration of the pre-quarry scenario was taken as the ReFH2.3 recommended storm duration of 2.5 hours, reflecting the lack of attenuation in the catchment prior to the quarry development.

For the post-quarry scenario, it was necessary to simulate the model for a range of storm durations to establish the critical storm durations (CSD). This is because the initial storm duration ReFH2.3 estimates are unlikely to result in the greatest flood levels given the lake attenuation is represented in the model and not the hydrology. As shown in Figure 3.3a range of storm durations were simulated in the hydraulic model to determine which duration which gives the highest peak outflow. This showed that the storm duration of 99-hours gave rise to the largest flows. It is evident that the longest duration tested results in the largest flows discharging from the post-quarry system. It remains possible that the true critical duration may even exceed 99 hours, but limitations of the ReFH2.3 software prevents this from being tested.

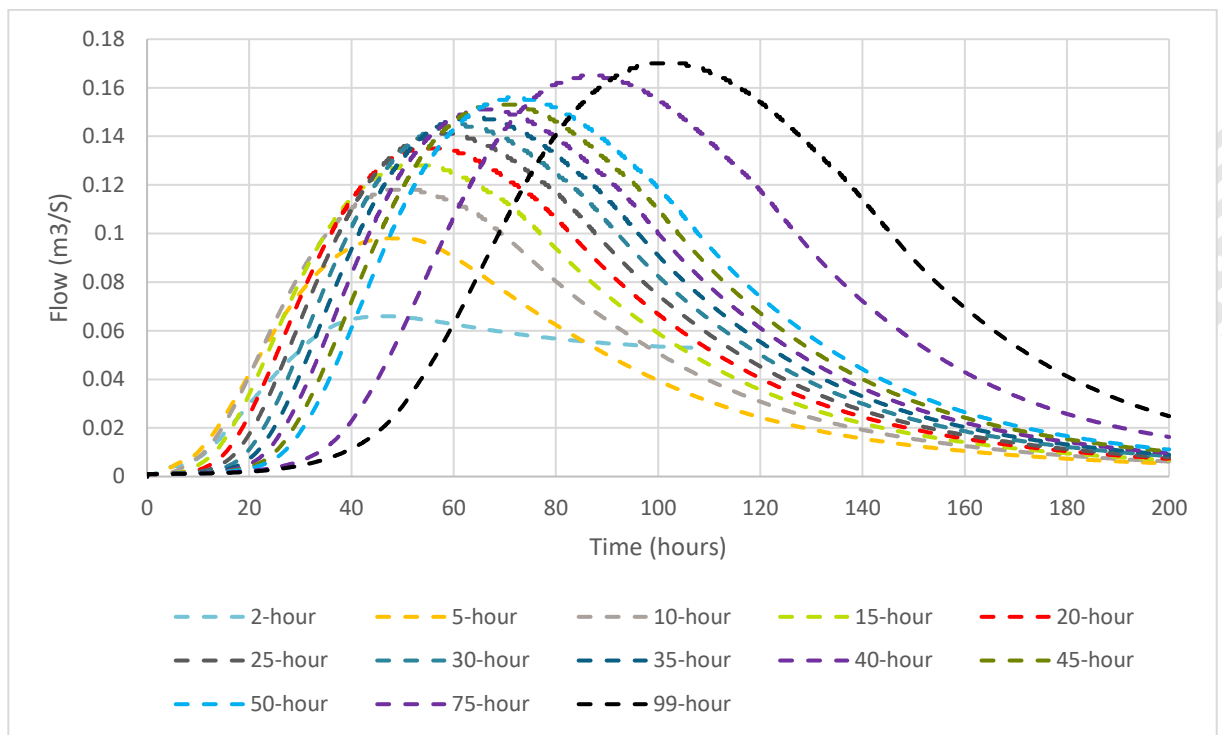


Figure 3.3: Graph showing the results of critical storm duration testing

99 hours represents a very long critical duration compared to that seen on many catchments. The reason for this is simply illustrated in Figure 3.4 which shows that as the catchment area increases so does the percentage covered by lakes. This is a simple demonstration of how each subsequent lake within the system is likely to increase the associated attenuation and therefore the critical storm duration. **At the outflow of Q3, the lake's influence is at its greatest at any point within the catchments.**

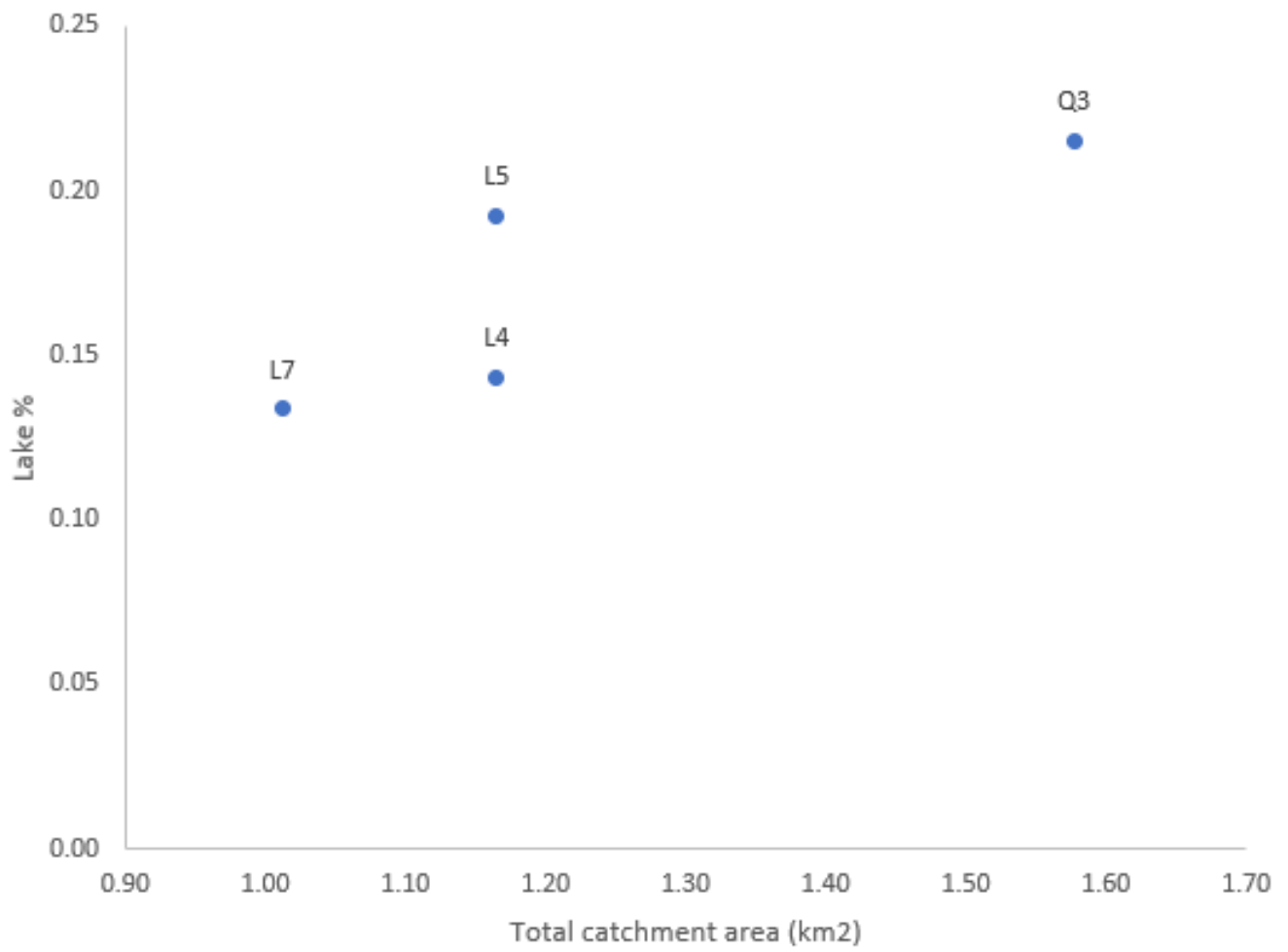


Figure 3.4: Percentage of lakes within the total catchment area

4 Results

This chapter provides an overview of the model results. Flows referred to here represent the catchment outflows to the SSSI. In the post-quarrying scenario this represents outflow from Q3.

4.1 Pre-quarry against post-quarry (2.5hr CSD)

Pre-quarry flows from the system were taken directly from ReHF2.3. Post-quarry estimates of flow from the development site during storm events were obtained using the ReFH2.3 flows to generated from areas draining to the lakes and run through the hydraulic model. The effect of the extensive lake system is to lower the peak flows and extend the hydrographs. To allow a like-for-like comparison, pre and post quarry flows presented in Figure 4.1 both using a storm duration of 2.5 hours (only critical for the pre-quarry scenario). This shows how the pre-quarrying peaks occurred at around 2.5-hours with the post-quarry peaks occurring at around 7-hours. Table 4.1 shows that the peak pre-quarrying flows are around five times higher than those which may occurring following the post-quarry.

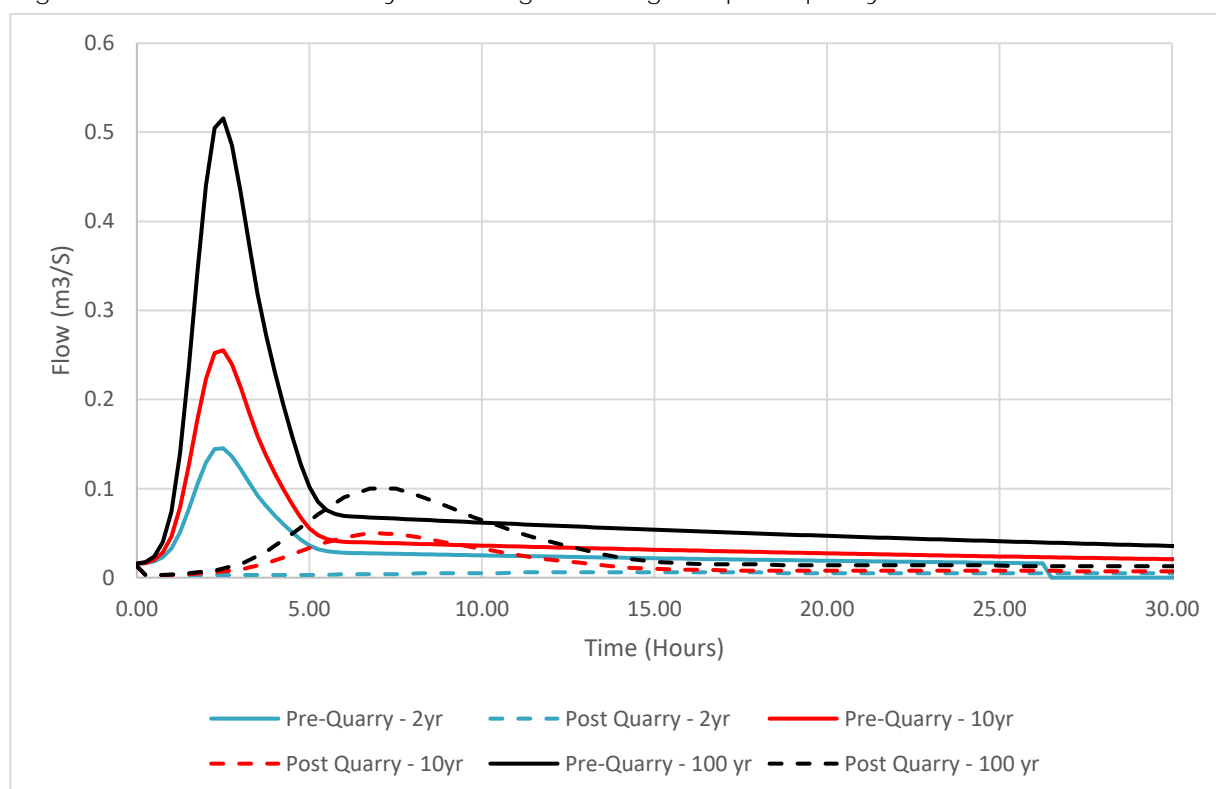


Figure 4.1: Pre-quarry flows against post-quarry flows

Table 4.1: Peak flows of the pre-quarry against post-quarry

Return Period	Pre-Quarry Flows (m ³ /s)	Proposed Catchment Flows (m ³ /s)
2	0.15	0.03
10	0.26	0.05
100	0.52	0.10

4.2

4.3 Pre-quarry against post-quarry (99hr CSD)

The pre- and post-quarry scenario flows were also produced for the 99-hour storm event, critical only for the post-quarry event. Figure 4.22 shows the pre-quarrying peaks occurred at around 50-hours with the post-quarry peaks occurring at around 350-hours. Table 4.2 shows that the peak post-quarrying flows are 0.02m³/s higher than those which may occur during the pre-quarry scenario for this particular storm duration.

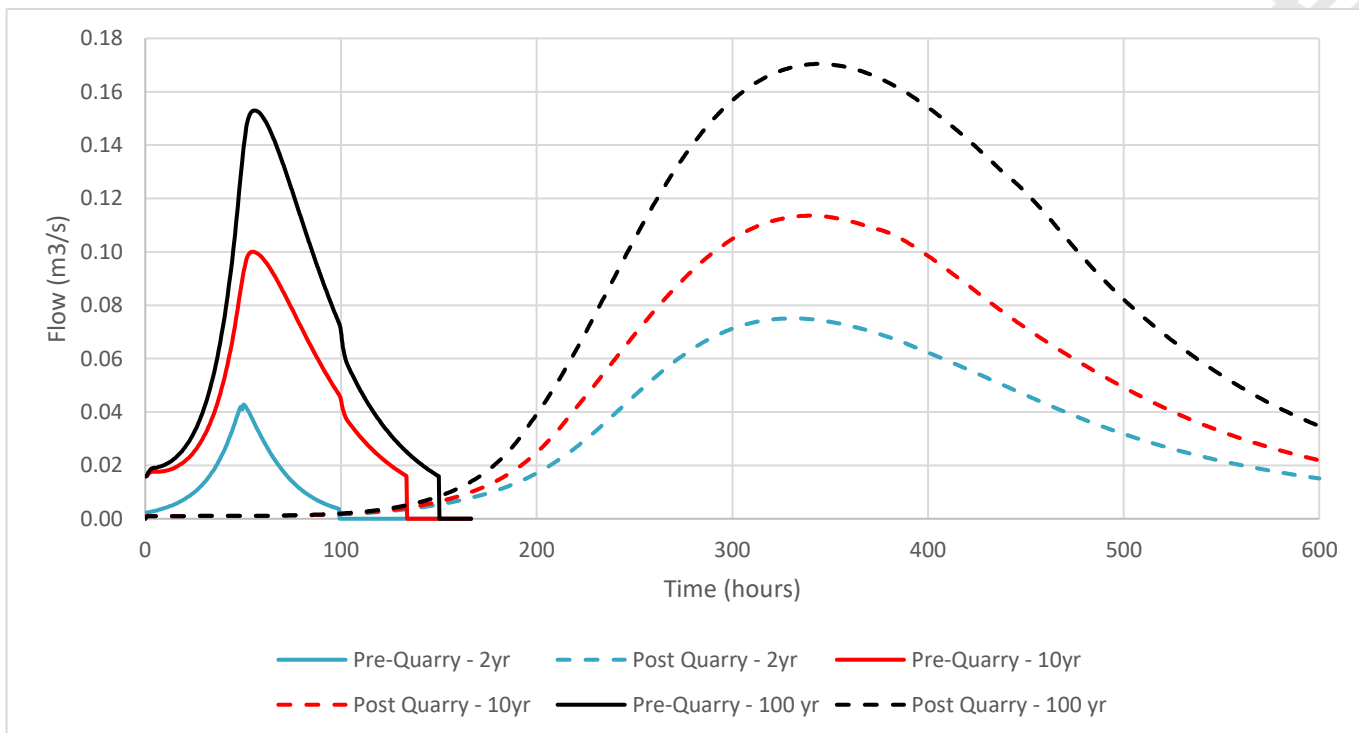


Figure 4.2: Pre-quarry flows against post-quarry flows (99hr)

Table 4.2: Peak flows of the pre-quarry against post-quarry (99hrs CSD)

Return Period	Pre-Quarry Flows (m ³ /s)	Proposed Catchment Flows (m ³ /s)
2	0.04	0.07
10	0.10	0.11
100	0.15	0.17

4.4 Critical events for both scenarios

Although not comparing like-to-like storms, the best comparison between pre- and post-quarry scenarios is using a storm duration critical for each scenario. Figure 4.3 and Table 4.3 below show the results (a 2.5-hour CSD for pre-quarry and 99-hour CSD for post quarry). This shows the likely worst-case flows on each catchment.

This demonstrates how in a worst-case scenario on each catchment, post-quarry flows are significantly reduced from the pre-quarry scenario.

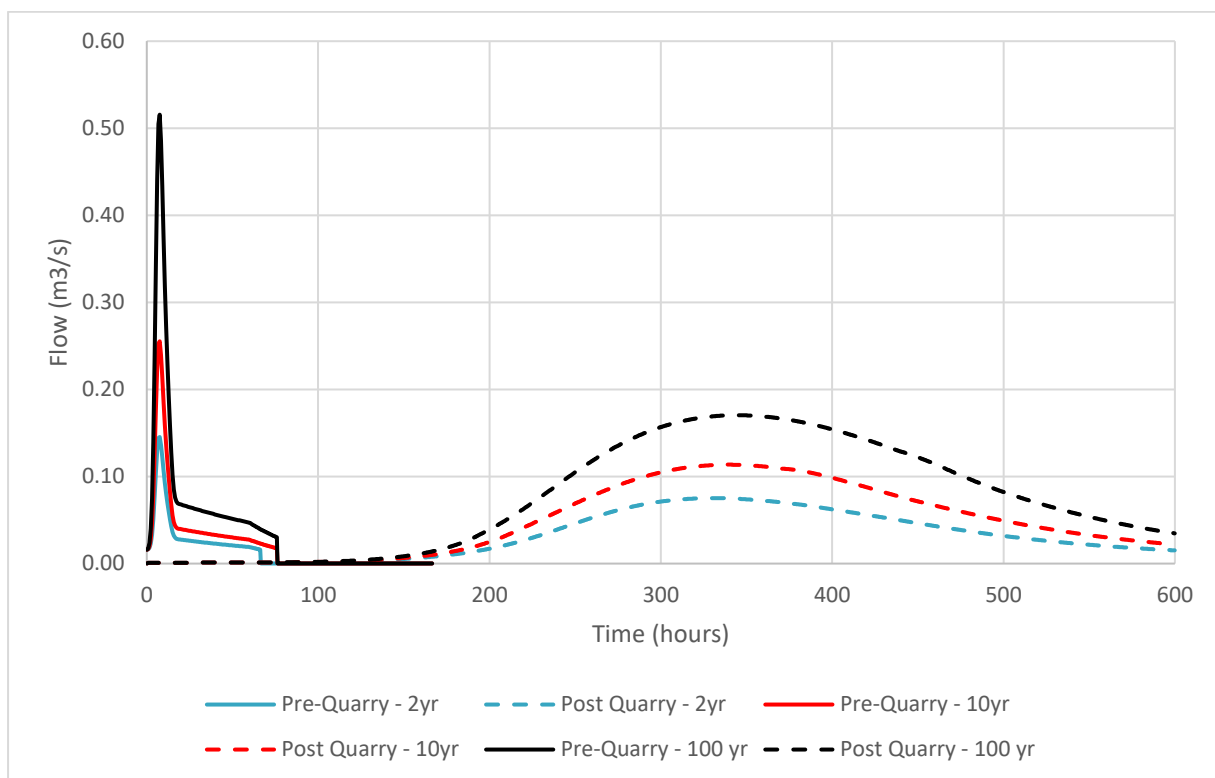


Figure 4.3: Flow for the critical events for both scenarios

Table 4.3: Peak flows of the critical events for both scenarios

Return Period	Pre-Quarry Flows (2.5 hours) (m³/s)	Proposed Catchment Flows (99-hours) (m³/s)
2	0.15	0.07
10	0.26	0.11
100	0.52	0.17

4.5 Sensitivity Results

The following sensitivity test was undertaken and applied to the 100-year return period.

- $\pm 20\%$ change to structure coefficients

Table 4.4: Sensitivity results

Test	Maximum increase to outflow (m³/s)	Maximum decrease to outflow (m³/s)
Plus 20% structure coeff*	0.01	0.00
Less 20% structure coeff*	0.00	-0.01

Table 4.44 shows that changing the structure coefficients resulted in minor changes to the average water levels.

5 Assumptions

The following project-specific assumptions have been made during this modelling project (beyond those inherent across all modelling projects):

- The results are based on an outline drainage strategy. If there is further development of drainage strategy, where significant changes to the routing of flow through the site, or the levels of the lakes, the modelling may need to be re-evaluated.
- Pre-quarrying flows are based on a catchment area which is thought to reflect the area pre-1957. There is clearly some uncertainty in the true nature of the catchment some 60 years ago.
- The LIDAR represented up to date and accurate ground levels in areas where no topographic survey information is available.
- It is assumed all lakes within the system have a starting water level matching the invert level of the culverts / orifices draining each lake.
- The hydrology and modelling have not been designed to cover the requirements of reservoir studies as per the Reservoirs Act (1975), such as modelling of the Probable Maximum Flood. It is JBA's understanding that the recent construction of a spill way channel means that the Q3 no longer comes under the Act.

6 Conclusions

The following conclusions can be drawn from the current modelling project:

- Modelling indicates that peak flows down the SSSI catchment have been reduced by the changes in catchment shape and the attenuating effect of the lakes. The effect of the extensive lake system is to lower the peak flows and extend the hydrographs. This is evident in the pre-quarrying peaks occurring at around 2.5-hours with the post-quarry peaks occurring at around 7-hours.

A Appendix A: FEH calculation record



Flood estimation report: Moneystone Quarry

Introduction

This report template is based on a supporting document to the Environment Agency’s flood estimation guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

1	Method statement	3
2	Catchment Descriptors	6
3	Revitalised flood hydrograph 2 (ReFH2) method	8
5	Discussion and summary of results	11

Approval

	Name and qualifications	Date
Method statement prepared by:	Katherine Dixon MPhys Geog, PgCert	04.10.2021
Method statement reviewed by:	Kevin Haseldine BSc MSc MCIWEM C.WEM	05.10.2021
Calculations prepared by:	Katherine Dixon MPhys Geog, PgCert	04.10.2021
Calculations reviewed by:	Kevin Haseldine BSc MSc MCIWEM C.WEM	05.10.2021

Revision History

Revision reference	Date issued	Amendments	Issued to

Abbreviations

AMAX.....	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CPRE.....	Council for the Protection of Rural England
FARL.....	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED.....	Median Annual Flood (with return period 2 years)
ReFH.....	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBEXT1990.....	FEH index of fractional urban extent
URBEXT2000.....	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

Note on flood probability

This document quotes the probability of a flood magnitude in terms of a return period based on analysis of annual maximum (AMAX) floods. The return period of a flood on the AMAX scale is the average interval between AMAX floods of that magnitude or greater. The inverse of the AMAX return period is the annual exceedance probability (AEP).

Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. AEP can be helpful when presenting results to non-specialists who may associate the concept of return period with a regular rather than an average interval.

Return period can also be measured on the peaks-over-threshold (POT) scale as the average interval between floods of that magnitude or greater. The difference between AMAX and POT return periods is only important for short return periods (under 10 years).

The table below is provided to enable quick conversion between these different measures.

AMAX return period (years)	n/a	2	5	10	20	30	50	75	100	200	1,000
AEP (%)	n/a	50	20	10	5	3.33	2	1.33	1	0.5	0.1
POT return period (years)	1	1.5	4.5	9.5	20	30	50	75	100	200	1,000

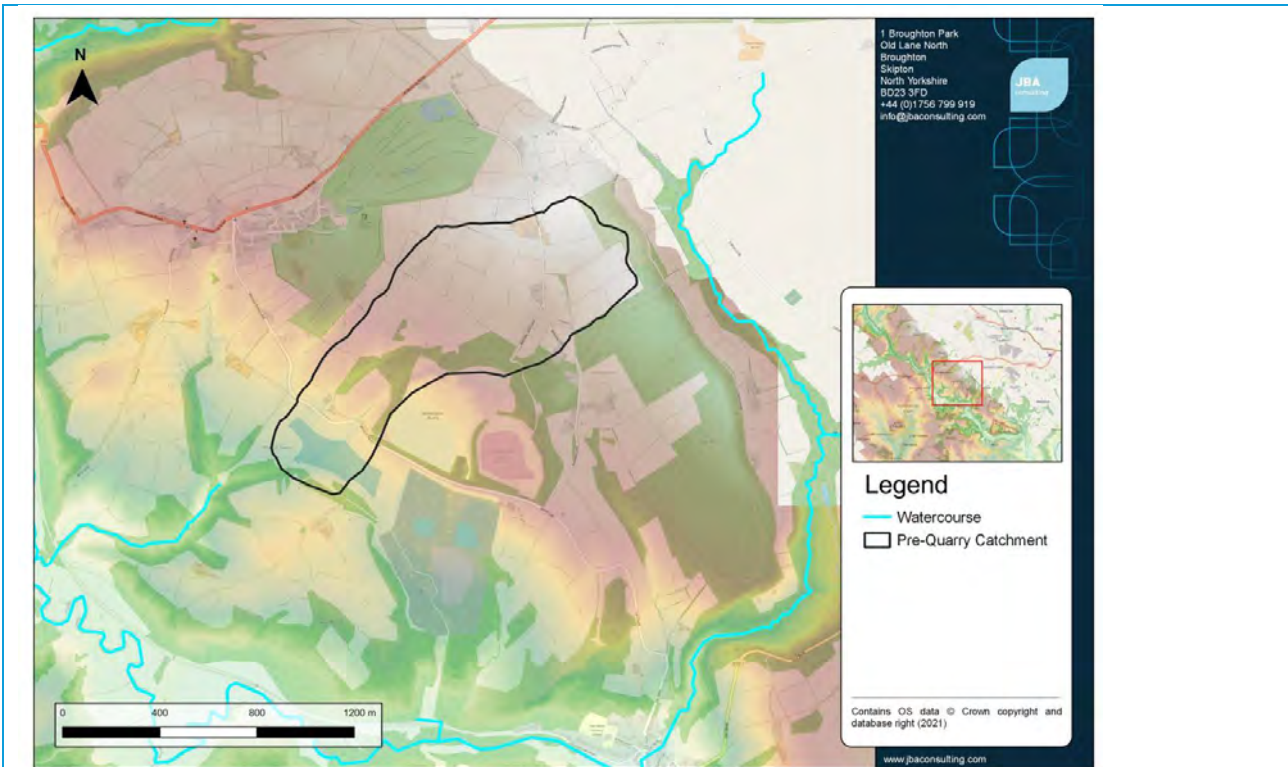
1 Method statement

1.1 Requirements for flood estimates

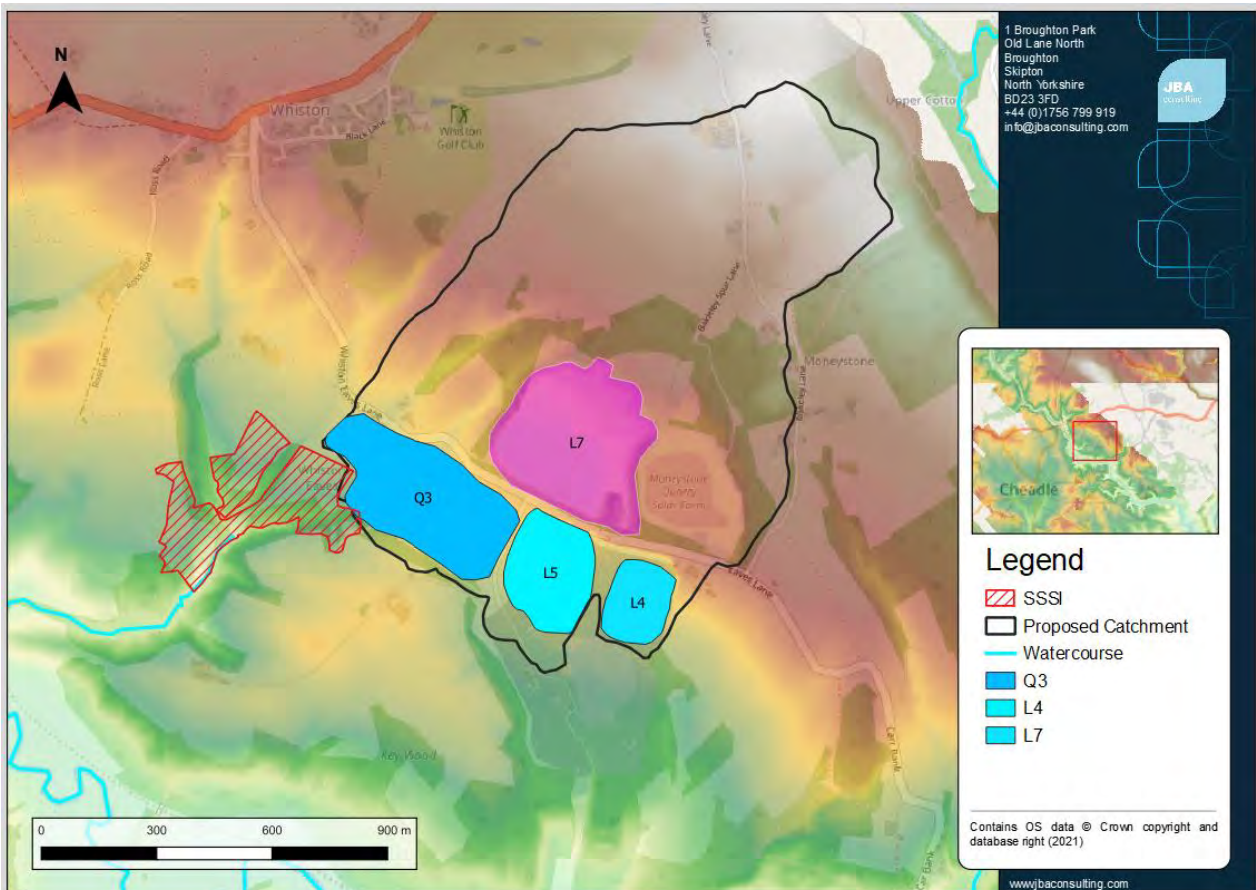
<p>Overview</p>	<p>The Moneystone Quarry development site is located approximately 1km south-east of the village of Whiston in northern Staffordshire, centred at National Grid Reference SK 04553 46124. After the cessation of quarrying in December 2010, the site comprises a series of ponds surrounded by a mixture of wetlands, grassland, woodland and shrubland. Whiston Eaves Site of Special Scientific Interest (SSSI) is located approximately 300m southwest of Q3, which is the largest pond within the former quarry. The proposed development seeks to incorporate a new leisure park development which will result in the generation of three attenuation lakes where water will flow westwards from L4 → L5 → Q3 through an array of open channels.</p> <p>Several unnamed tributaries of the River Churnet flow through the Moneystone Quarry development site area, predominantly in a south-east direction. The catchment boundaries for these streams have changed over time due to the changing nature of the ground surface during quarrying, hence altering the surface water drainage paths. In order to understand how the catchment boundaries have changed, it is necessary to explore the catchment boundaries at three points in time: pre-quarry (pre-1957), present day conditions and proposed catchments following completion of the new leisure development.</p> <p>Design flood estimates and hydrographs are needed for the pre-quarry and proposed catchment scenarios for the 2-year, 10-year and 100-year return periods using the methods set out in the Flood Estimation Handbook (FEH).</p> <p>A 1D model of Moneystone Quarry pond system site is required to assess the impact of flows on the SSSI for the proposed catchment scenario.</p>
-----------------	---

1.2 The catchment

<p>Maps</p>
<p>The pre-quarry catchment was based on topography before the quarry was established.</p>



Whereas the proposed catchment incorporates information from the drainage strategy which will see the inclusion of three attenuation ponds (L4, L5 and Q3) and diversion of the current flow paths.



Description	The ground surface within the site area slopes generally down to the southwest, with elevations ranging from 131m AOD at the downstream
-------------	---

	<p>extent of the SSSI (south-west of Q3 quarry) to a ridgeline with a high point of 293mAOD, located approximately 1km north-east of the quarry.</p> <p>Soil classification by the Soil Landscapes Online Viewer (DEFRA, 2021) have revealed the site area to have multiple soil types. Slowly permeable seasonally wet loamy and clayey soils are located immediately south of Q3 reservoir, while freely draining slightly acidic loamy soils surround the quarry area and underlies the majority of the SSSI. In addition, freely draining very acidic sandy and loamy soils underly the eastern half of Moneystone Quarry.</p>
--	--

1.3 Initial choice of approach

Is FEH appropriate?	Yes
Initial choice of method(s) and reasons	Flow estimates for the three catchment scenarios will be generated using the ReFH2.3 method. This is deemed appropriate as it allows the generation of design hydrographs for rural ungauged catchments and include estimation of hydrograph volume (unlike FEH Statistical) which is essential for a system with a pond / lake network.
Software to be used	FEH Web Service ¹ /ReFH2.3/ Flood Modeller Pro

¹ CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, Oxon, UK.
2021s0663 – Moneystone Quarry FEH Calculations

2 Catchment Descriptors

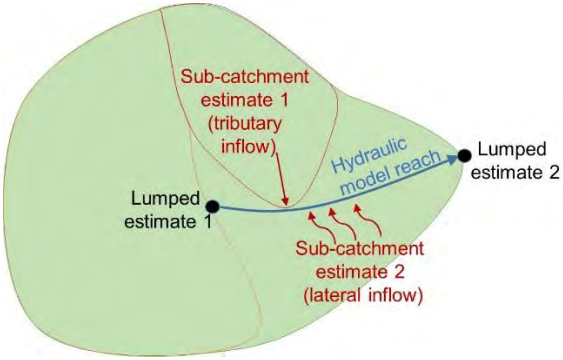
Separate lumped flow estimation points will be used to represent the total inflows for the pre-quarry, current and proposed catchments.

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Easting	Northing	AREA (km ²)
Pre-quarry catchment	Lumped	404050	346150	0.78
Proposed catchment (Upstream)	Lumped	404050	346150	1.01
Proposed catchment (Lakes)	Lumped	404050	346150	0.15
Proposed catchment (Q3)	Lumped	404050	346150	0.14

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.
 Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced.
 The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Catchment descriptors used in the analysis are recorded below. Those changed from the FEH CD-ROM are highlighted in bold. Whilst a series of lakes are present in the study area, these are represented in the hydraulic model and therefore FARL has been set to 1.0 to prevent double counting. The pre-quarry catchment included no online lakes or ponds.

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	SAAR (mm)	URBEXT 2000	FPEXT
Pre-quarry catchment	1	0.44	0.729	0.875	936	0	0.0048
Proposed catchment (Upstream)	1	0.44	0.729	1.007	936	0	0.0048
Proposed catchment (Lakes)	1	0.44	0.729	0.357	936	0	0.0048

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	SAAR (mm)	URBEXT 2000	FPEXT
Proposed catchment (Q3)	1	0.44	0.729	0.343	936	0	0.0048

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	<p>The pre-quarry catchment boundaries were derived using OS maps prior to the start of quarrying (pre – 1957) which show topographic contours of the landscape. These were used in conjunction with the OS Panorama DTM dataset to delineate the catchment boundaries. The OS Panorama DTM is a now superseded DTM that was based on the contours on OS contour maps, and thus was based on the topography before the quarry was established.</p> <p>The proposed catchment boundaries were derived using 2m LIDAR to provide a depiction of the likely drainage routes of surface water throughout the catchments, following excavation and movement of the ground surface. Based on the drainage strategy plans, the catchments boundaries have been amended to represent the change in flow paths which will be diverted as a result of the development.</p>
Record how other catchment descriptors were checked and describe any changes.	The BFIHOST values were checking using the knowledge of the catchment geology and were deemed appropriate.
Version of URBEXT	URBEXT2000
Method for updating of URBEXT	CPRE formula from 2006 CEH report on URBEXT2000
Source of BFIHOST	BFIHOST19 was used in the ReFH2 calculations, since the current release (ReFH2.3) was calibrated using BFIHOST19.

3 Revitalised flood hydrograph 2 (ReFH2) method

3.1 Parameters for ReFH2 model

In accordance with research findings, all catchments with URBEXT2000 up to 0.30 were modelled as if they were rural. Research on flood estimation in small catchments² found that flood frequency estimates on such catchments were more accurate if the catchment was treated as rural. This reflects the difficulty of generalising the complex and locally specific effects that urban development has on flood flows.

All catchments					
Only extremely heavily urbanised catchments					
Site code	Method	C_{max} (mm)	T_{prural} (hours)	BL (hours)	Area of catchment modelled as urban (km ²)
Pre-quarry catchment	Catchment Descriptors	701	1.08	36.22	N/A
Proposed catchment (Upstream)	Catchment Descriptors	701	1.17	37.35	N/A
Proposed catchment (Lakes)	Catchment Descriptors	701	1.00	29.77	N/A
Proposed catchment (Q3)	Catchment Descriptors	701	1.00	29.53	N/A
Version of the ReFH2 model applied	ReFH2.3 using the water balance option. This treats BR (baseflow recharge) as a state variable rather than a parameter, setting it automatically in order to conserve volume. The values of BR vary with return period and so are not reported here.				
Parameters for urban runoff model	<p>The impervious fraction of urban areas, IF, was kept at its default of 0.4.</p> <p>The impervious runoff factor, IRF, (which can also be interpreted as the fraction of the impervious surface that is positively drained) was kept at its default of 0.7.</p> <p>The depression storage was kept at its default of 0.5mm.</p> <p>T_p for runoff from areas modelled as positively drained was calculated as 0.75 times T_{prural}.</p>				
Methods: OPT: Optimisation from fitting to observed flow data, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)					

3.2 Design events for ReFH2 method: Lumped catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
Pre-quarry catchment	Rural	Winter	2.15

² Stewart, Lisa, Duncan Faulkner, Giuseppe Formetta, Adam Griffin, Tracey Haxton, Ilaria Prosdocimi, Gianni Vesuviano and Andy Young (2021). Estimating flood peaks and hydrographs for small catchments (Phase 2). Report – SC090031/R0, Environment Agency.

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
Proposed catchment (Upstream)	Rural	Winter	2.15
Proposed catchment (Lakes)	Rural	Winter	2.15
Proposed catchment (Q3)	Rural	Winter	2.15

3.3 Critical Storm Duration Testing

Sensitivity testing on the critical storm durations has been completed, as the initial storm duration ReFH2.3 estimates may not always result in the highest peak flow or account for the attenuation of the lakes within the system. As shown in Figure 3.1 a range of storm durations were assessed through the hydraulic model to determine which duration gives the highest peak flow. This showed that the storm duration of 99-hours was the most critical.

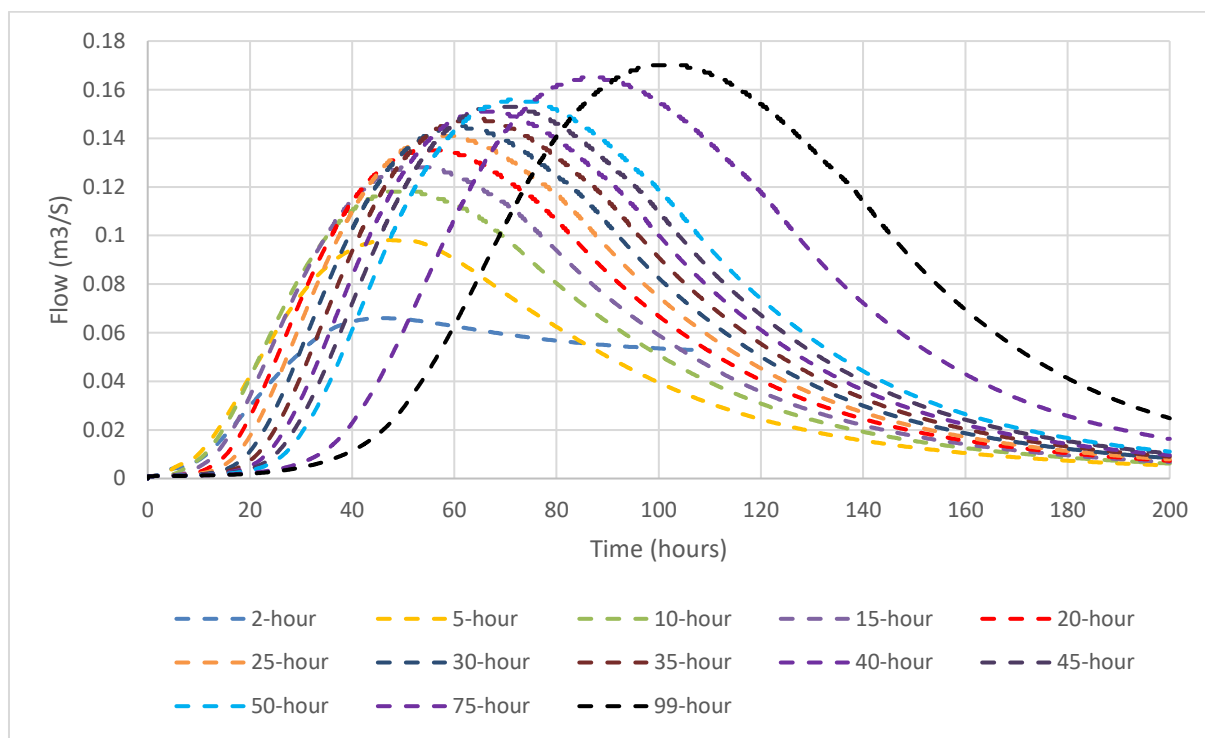


Figure 3.1 – Graph showing the critical storm duration testing for the 100-year event

3.4 Flood estimates from the ReFH2 method

Site code	Flood peak (m³/s) for the following return periods (in years)									
	2	10	20	30	50	75	100	150	200	1000
Pre-quarry catchment	0.15	0.26	0.31	0.35	0.42	0.47	0.52	0.58	0.63	0.96
Proposed catchment (Upstream)	0.18	0.31	0.39	0.43	0.51	0.58	0.63	0.71	0.78	1.17

Site code	Flood peak (m ³ /s) for the following return periods (in years)									
	2	10	20	30	50	75	100	150	200	1000
Proposed catchment (Lakes)	0.03	0.05	0.07	0.07	0.09	0.10	0.11	0.12	0.13	0.20
Proposed catchment (Q3)	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.19

5 Discussion and summary of results

5.1 Final choice of method

Choice of method and reasons	ReFH2.3 has been selected as the final choice of method as it is able to generate design hydrographs for rural ungauged catchments. It's inherent inclusion of volume is essential for the current project where the area of interest is dominated by a series of lakes and ponds.
How will the flows be applied to a hydraulic model?	Flows will be applied to the hydraulic model as lumped estimates. Critical storm duration will be established within the model.

5.2 Assumptions, limitations and uncertainty

List the main assumptions made	The main assumption is related to the catchment boundary for the Moneystone catchment, which is solely based on LiDAR and local knowledge.
Discuss any particular limitations.	No flow data is available due to the catchments being ungauged.
Give what information you can on uncertainty in the results	<p>The flow estimates have been calculated based on catchment descriptors alone. If flow data had been available at the time of the assessment, the associated uncertainty could have been reduced.</p> <p>The catchment boundaries have been estimated from the FEH Web Service drainage network, LiDAR data and local knowledge from site visits.</p> <p>There are no standardised methods available for estimating uncertainty bands for the ReFH2 model, given the more complex nature of the method and large number of inter-dependent "moving parts" in the model.</p>
Comment on the suitability of the results for future studies	The calculations could be useful in future studies if assessments are required for sites nearby, and to provides results to compare any future studies in the catchment area with. Spot gauging measurements may be useful in future studies.

5.3 Final results

Site code	Flood peak (m ³ /s) for the following return periods (in years)									
	2	10	20	30	50	75	100	150	200	1000
Pre-quarry catchment	0.15	0.26	0.31	0.35	0.42	0.47	0.52	0.58	0.63	0.96
Proposed catchment (Upstream)	0.18	0.31	0.39	0.43	0.51	0.58	0.63	0.71	0.78	1.17
Proposed catchment (Lakes)	0.03	0.05	0.07	0.07	0.09	0.10	0.11	0.12	0.13	0.20
Proposed catchment (Q3)	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.19

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below)	Results - Hydraulic Model Inflows
---	-----------------------------------

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